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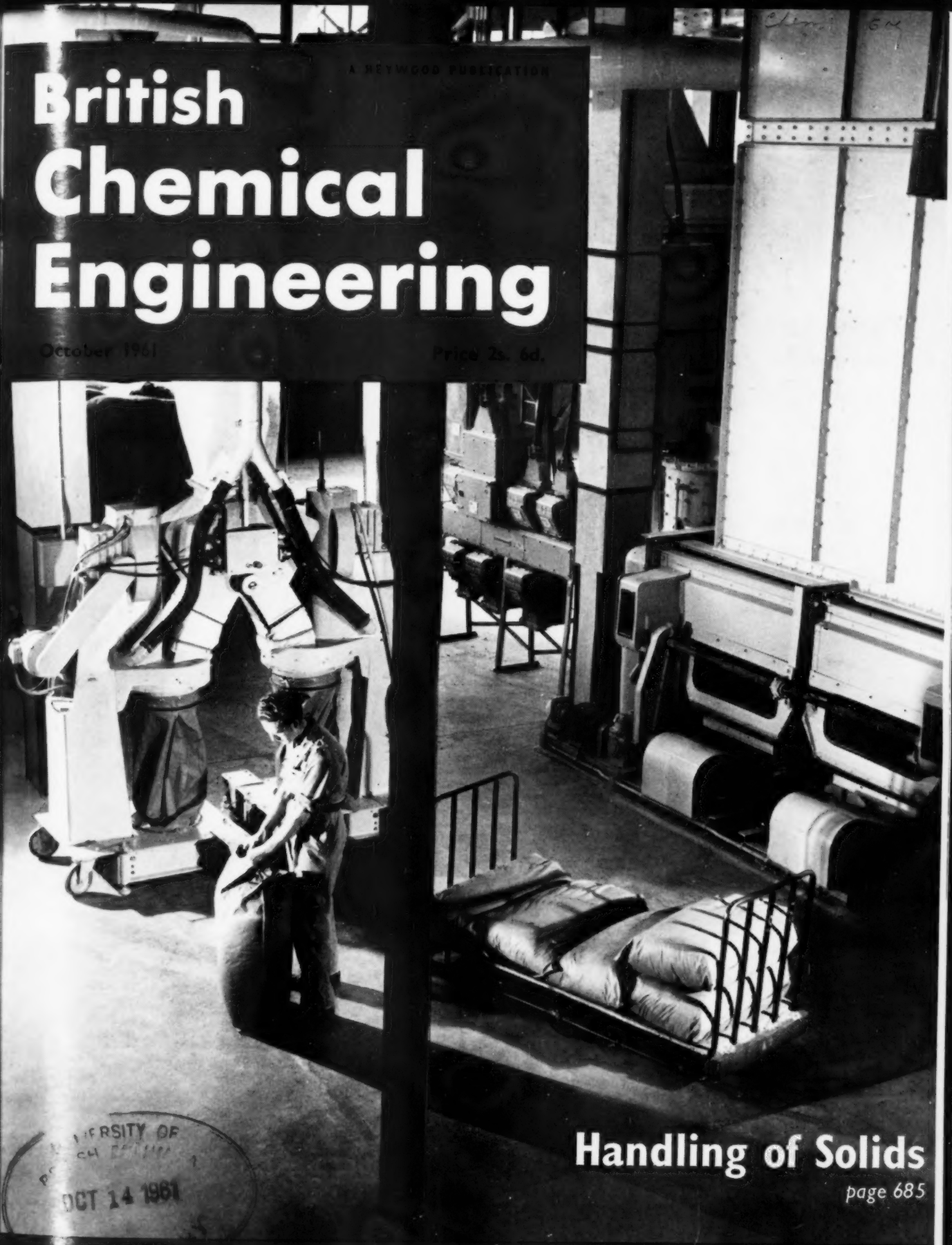

UNIVERSITY OF
OCT 14 1961

Handling of Solids

page 685

...ique of Liquid-Liquid Extraction (page 676)
Solving Transient Heat Transfer Problems (page 680)
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Mass Transfer Applications (page 692)

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DIGEST OF INDUSTRIAL AND TECHNICAL DEVELOPMENTS

Flow Measurement of Coarse Suspensions

PIPE BENDS, venturis and a new device, the vertical counterflow meter are all useful as instruments for metering the flow of liquids containing pieces of solid matter rather than very small particles.

Work on apparatus of this type as well as upon a newer device, the vertical counter flow meter is to be described in a forthcoming paper to be given by DR. BROOK of Leeds University*.

The solids used were bakelite of sp. g. 1.35 and basalt sp. g. 2.82, and the results obtained with venturis installed either horizontally or vertically, show that the liquid-solid system behaves as a dense liquid. Discharge coefficients approached the values of water when the sp. gr. of the mixture is taken into account; this is most easily done by expressing the differential head generated by the meter as head of mixture rather than as head of water.

In the case of pipe bends, by contrast, the discharge coefficients were closer to those of clear water if the differential pressure across the bend was expressed in feet of water. Hence the bend can rather surprisingly be used to meter the flow of a liquid-solid mixture even though the sp. gr. of the solid or its concentration is unknown or variable.

The vertical counterflow meter offers another means of calculating the flow velocity when the quantity of solids is unknown; it compares the pressure losses in two similar vertical lengths of piping one with the flow upwards the other with it downwards. The difference between the two losses is a measure of the solid sp. gr., and their sum, from which the velocity can be calculated, is the total loss due to hydraulic friction.

This meter is effective when the flow velocity is high enough to nullify the vertical slip of the particles.

* To be published in Vol. 176, Trans. I. Mech.E.

The Location of Refineries

THE problem of locating a refinery does not seem to have a straightforward solution, partly due to the fact that there are a number of mostly contradictory elements which influence the people who have to make this decision. There is, so to speak, a tug-of-war of motives for locating the refineries as near as possible to the oil fields and, on the other hand, locating them as near as possible to the consumer.

Up to certain limits, the bigger the refinery the lower the unit cost, provided the capacity can be fully utilized in the areas supplied by the refinery. This is dependent on the relationship between the yield pattern of an economically designed refinery, and the consumption pattern in the consumer area. Before the war, Europe had a small demand for residual fuel oil and large refineries could, therefore, not be built in Europe because they would have been left with surplus residual oil for which there was no local market. There is now a demand for practically all the yields that can economically be made, and this has resulted in a spectacular development of consumer oriented refineries in Europe.

In the last few years it has become clear that above a capacity of above 3m tons/year the economics of scale become small, due to the size limitation of single units and the necessity to build 2 or more. The result has been more refineries built nearer the consumer area.

The location of refineries is greatly influenced by the difference in transport costs of crude and finished products. This difference has continued to grow in favour of locating refineries near the consumer centres. The recent development of inland pipelines also favours location near consumer centres.

An example of political factors which determine refinery location is the newly independent African countries which all want a refinery, even though it may not be economically justified, and the recent agreements between some African countries and the Italian State-owned petroleum organization.

Whereas about two-thirds of the refining capacity, outside North America and the Soviet bloc, was resource-located before the war (located near an oil field and products shipped to distant markets), the proportion was half and half in 1951 and over 60% of capacity is now market-located. This trend is likely to continue.

From "The Location of Refineries" P. H. FRANKEL and W. L. NEWTON, *Inst. Pet. Rev.* 1961 **15** (175) 197-201.

How is your Particle Balance?

A PROBLEM which often confronts the research worker in the field of fine particles is the preparation of the particles under controlled conditions, in order to provide specified physical dimensions and chemical composition; this costs time and money. To meet this difficulty the Stanford Research Institute, Menlo Park, California, has established a bank of fine particles from which samples can be drawn by research organizations, and to which payments of samples can be made.

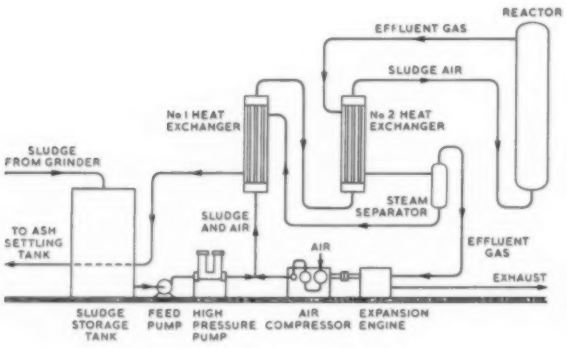
Any body which acquires through its work a supply of particles suitable for a research study, is encouraged to supply the bank with any surplus of the material which it can spare, together with as complete a story of the particles as it can provide. The bank will store a material, and offers samples of it along with its relevent details, to any organization that may have need, for the very modest handling fee of $10 per sample.

To date the bank has a "capital" of some 130 samples with a wide range of chemical and physical compositions. Among them are particles of carbon black and clay, puff-ball spores, glass beads, coffee-roast soot, fly-ash, titanium dioxide, tungsten, and polystyrene spheres. Many are available in a wide range of size distributions. For example, the glass beads of nearly spherical shape, can be supplied in sizes as small as 1 micron. The polystyrene spheres are even smaller—as little as ¼ micron.

Flameless Combustion of Sludge

THE disposal of organic waste of all kinds is a matter of increasing public concern. Substantial improvements in disposal methods have been effected but even the best available methods only partially solve the social and economic problems which are involved.

Details of a process which burns sewage sludge effectively and economically, in its aqueous state, at low temperatures and without flame, are now given by the inventors.* The Zimmermann Process operates on the principle that organic matter can be efficiently oxidised in an aqueous dispersion at a lower temperature than in conventional combustion. A significant feature of this process is that once " burning " is initiated it will continue unassisted by any external heat source, as long as air, water, and combustible sludge continue to be fed to the system.



In this Process the fuel is free, water is essential to the continuity of combustion, and the air costs money because its quantity and pressure must be carefully controlled. The flow diagram decribes the process system which is all kept at constant pressure. Sludge is continuously pumped into a reactor with the required amount of air at specified temperatures and pressures. Flameless combustion takes place as the oxygen in the air combines with the organic matter in the sludge to form carbon dioxide, nitrogen and steam. The ash remains in the residual water and can be pumped to a lagoon or fill because it is biologically stable. The exhaust gases are expanded to run an air compressor or generator. When there is an adequate concentration of volatile matter in the sludge, the Process will require no external power. The residual hot water from the reactor is utilised to preheat the incoming sludge and air to about 400°F, the temperature at which oxidation will start in the reactor.

The combustion of unconventional fuels, having low BTU values, proceeds efficiently because fuel values vary little per pound of air consumed.

Among the advantages claimed for the Zimmermann Process are the following:

1. Ultimate sludge disposal.
2. No odour or air pollution.
3. Dewatering equipment is not required.
4. Low combustion temperatures.
5. All process streams conveyed by pumping.
6. Not " temperamental " as bacterial processes.
7. Low operating and maintenance costs.
8. Very low power costs.

A new small unit, a further development of this process, is to be described this month at the American Pollution Federation conference.

* Sterling Drug Inc., 1450 Broadway, New York 18, N.Y. U.S.A.

Tantalum in Chemical Plants

IN the search for new materials of construction for chemical plants, one of the most promising materials considered so far is the rare metal tantalum, a bluish grey metal which looks like platinum and has the corrosion resistance of glass. It is rare, the processes for recovering it are complicated and therefore its cost is high.

Metallurgists* are nevertheless studying methods of using it as a liner for large pressure vessels for, if it could be employed as a thin internal coating, the cost would not be prohibitive.

Tantalum presents several difficulties including the lack of know-how on fabrication of linings for large objects. The metal cannot be welded in the presence of air because under these circumstances it becomes brittle, and welding it to other materials like steel results in an imperfect bond.

To overcome the problem of making tantalum welds in air, engineers have adapted welding techniques in an inert argon atmosphere similar to those used for titanium. With tantalum, more accurate control of welding is necessary because it has a melting point of about 5425°F and a marked tendency to warp. Jigs and fixtures are used so that the back of the weld is protected with argon and warping is prevented. Objects of intricate shape are best welded in an argon-filled chamber or welding-box. The same method is recommended for welding connections to tubes of small diameter.

Since tantalum cannot be welded to steel, the attachment of a tantalum liner to a steel vessel requires special techniques similar to those applied for the construction of titanium linings, where strips of titanium are riveted on the inside of the vessel. Grooves of about 9mm are left between each pair of parallel backing strips which serve as channels to distribute the argon supply. Argon reaches these channels when it is fed to the reverse side of the weld via holes drilled through the steel wall of the vessel. The panels of lining material are attached to the backing strips by spot welding and inter-connected by means of overlapped fusion welds.

* Royal Dutch/Shell Laboratories, Amsterdam, Holland.

Fischer-Tropsch Process*

WORK on the Fischer-Tropsch process for the synthesis of oil and chemicals from mixtures of carbon monoxide and hydrogen was undertaken at the Warren Spring Laboratory to provide information for full scale development. It was mainly concerned with perfecting a liquid-phase system in which the reacting gases are passed through a suspension of iron catalyst in oil. This system is particularly suitable for use with a synthesis gas rich in carbon monoxide, such as may be produced from the complete gasification of coal. The work has involved development of a suitable catalyst, and the operation of the process on a pilot-plant scale to provide data for the design and operation of full-scale plant.

After studying the technical and economic possibilities of the production of oil from coal, the Committee on Coal Derivatives† concluded that the present cost of synthesis gas renders oil synthesis uneconomic in the United Kingdom. It considered that possible improvements in oil synthesis processes could exert only a marginal effect on the economics of an oil-from-coal plant, and that the technology of the Fischer-Tropsch synthesis was many years in advance of the possible development in gasification which alone could make oil synthesis viable. It accordingly recommended that work on the Fischer-Tropsch process at Warren Spring Laboratory should be wound up.

* From 1960 Annual Report of the Warren Spring Laboratory, Stevenage, Herts.

† Report of the Committee on Coal Derivatives, H.M.S.O., Cmnd. 1120, 1960.

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60 Years of Sodium Peroxide: A Historical Note

ALTHOUGH the 150 year old discovery of sodium peroxide by GAY LUSSAC and THENARD, when they burned sodium in air, occupies an important place in the history of this compound, an equally important event was the patent application of HAMILTON CASTNER, British Patent 20003 of sixty years ago. This protected the first successful production of the peroxide in tunnel kilns and was an outcome of CASTNER'S struggle to find new outlets for his extensive sodium production at Oldbury. Though DEVILLE'S production of aluminium in France by sodium displacement from a double chloride of aluminium is prominent in the literature, his work was surpassed by the Aluminium Company of Oldbury, where JAMES WEBSTER in company with CASTNER, built the world's largest works shortly before the advent of the electrolytic process.

Papers such as that given in 1889 by SIR HENRY ROSCOE to the Royal Institution testify to CASTNER'S achievements in developing sodium manufacture, which in turn paved the way to the economic production of sodium peroxide, sodamide and cyanide. After moving from New York to Lambeth, where he made his first sodium batches with support from the chemical engineer CULLEN, he was attracted to the Midlands by the Oldbury aluminium interests. There he established a full scale sodium industry which reduced the price of this metal from 14s. to one shilling per pound. GERHARD at Battersea had ceased operations because his sodium was too costly, while the BELL brothers, faced with WEBSTER'S Oldbury aluminium production which far exceeded theirs, and who were producing sodium and aluminium on Tyneside, also faded out. But at Oldbury, almost on the eve of the Hall-Heroult aluminium process, CASTNER worked his sodium process "from Sunday night to Saturday afternoon," week in week out, by means of 20 huge egg-shaped stills each 18 in. wide by 3 ft. high.

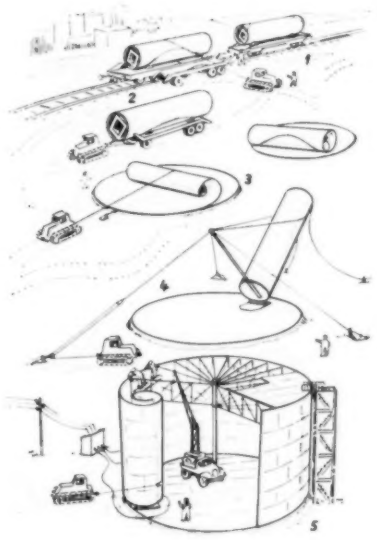
When, in 1890, the modern electrolytic process for aluminium left CASTNER with a large sodium production on his hands, the British sodium industry benefited from this apparent crisis. In 1888 came the patent for the Forrest-McArthur process whereby CASTNER produced cyanide from a fusion of sodium, charcoal and ammonia ; and then followed the outstanding master patent for sodium peroxide. In this process which enabled him to control the vigorous reaction of the two elements, he fed aluminium trays containing sliced sodium, a legacy from his aluminium process, continuously and counter-current-wise to a CO_2-free air stream in a kiln. He avoided too vigorous a combustion in the initial stages, while ensuring that the reaction was not inhibited by oxide films on the metal, with the result that a 95% peroxide was produced—no mean achievement considering that CASTNER had to design his plant from scratch.

Sodium peroxide was not only a contribution to the application of peroxide bleaching, but its reaction with borax in the presence of acid yielded sodium perborate. The process was adopted by the Niagara Electrochemical Company in America and by the Deutsche Gold und Silberscheide Anstalt in Germany. The site of manufacture in Britain moved to Runcorn from Oldbury as the Castner-Kellner interests developed, and the equipment included 80 ft tubular furnaces for sodium peroxide, and trays of stainless steel in place of the original aluminium. And in the board-room of Chance and Hunt at Oldbury are preserved even to this day, the absorbing documents containing inquiries into the credentials of "MR. HAMILTON CASTNER, known in New York as a chemist of good standing."

Erection of Storage Tanks by the Roll Method

A BRIEF outline of a rapid method of constructing storage tanks at site, developed by Czechoslovakian engineers, was given in our account of the 1960 Brno Engineering Exhibition. In this method the tank walls are fabricated from a continuous sheet which is wound helically and welded simultaneously, the entire operation being carried out automatically. This method enabled the refinery at Homs in Syria to be completed in a time comparable with the best world standards.

A somewhat different technique for tank manufacture has been employed in Poland and the Soviet Union, whereby the tanks are built from prefabricated sections, which are transported to the site in the form of large cylindrical rolls, and then erected. This roll method, whose sequence of operations is shown in the diagram, has proved particularly advantageous in the quick erection of large, cylindrical tanks.

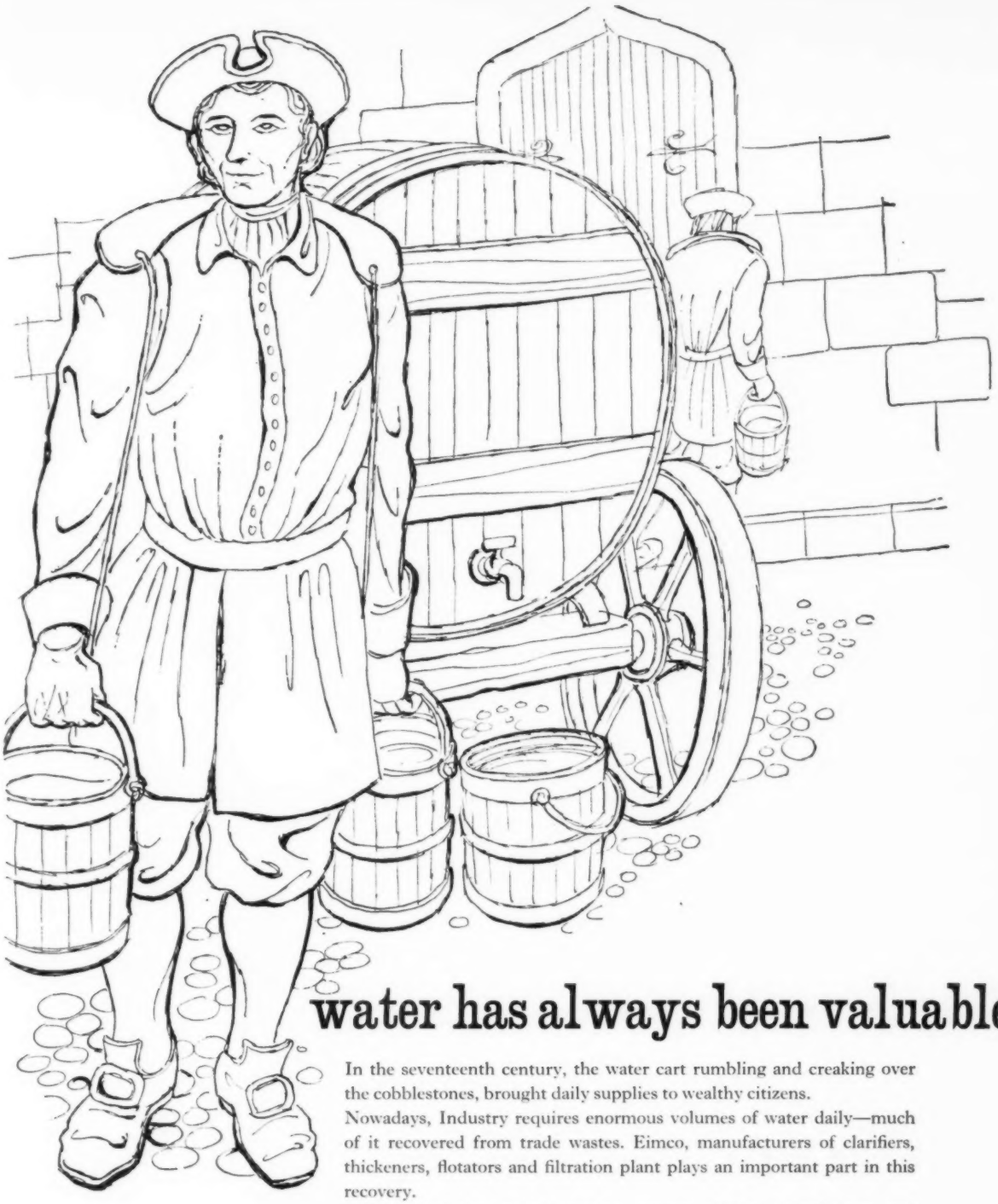


The bottom part of the tank and the wall are both welded and completely finished in the workshop, and each section is rolled into a cylinder. Each roof-truss leaves the workshop as a separate unit, and the roof-plates are assembled into complete sections ready for use.

At the site of erection the base of the tank is first laid on a previously constructed foundation ; then the wall roll is raised upon it. Next a centre strut is erected as part of the structure. The wall sheet is then rolled out and the radial trusses fitted by hand. The roof sections are put on and finally the wall joint is welded.

For a tank of 5000 m^3 volume, height 11.8m and diameter 23.6m, the base is made in two parts. The wall which is about 74m long, is rolled on to a frame. The diameter of the roll must not exceed 2.8m on account of its transport. The wall, built up from 5-13mm thick plates, has a total weight of 65 tons.

This method offers certain advantages over conventional methods in which all welding takes place on the building site. By fabricating the tank in the workshop, the various components can be assembled with greater accuracy and the welding may be done mechanically. In addition supervision of welding, for horizontal and vertical seams, and in particular the intersection between them is made much easier.



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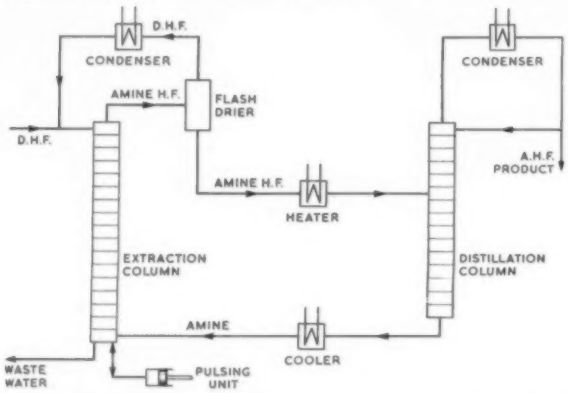
Amine Process for anhydrous hydrogen fluoride

A NEW process for the production of anhydrous hydrogen fluoride which has recently been developed by the Atomic Energy Establishment, Harwell, should be of interest to users and producers of anhydrous hydrogen fluoride alike, particularly in view of the substantial reductions in processing costs it provides. To illustrate this point we can mention that the current market price of A.H.F. is around £200 per ton. The estimated all-in production cost of A.H.F. by the new process for an output of 1000 tons per annum and assuming a weak acid concentration of 10%, is likely to be substantially less than £60 per ton. HF users will be able to recover HF as AHF from their process effluents thereby economising in the consumption of this expensive raw material.



Plants based upon this process, which can conveniently be called the amine process are now being offered by a British firm*. The salient features are outlined in the accompanying flow diagram; its essential steps are the contacting of HF in water with an amine by counter current flow through a pulsed column; the amine takes up the acid and a little water which is subsequently removed by flash evaporation and fractional distillation followed by separation of A.H.F. from the amine, which is recycled. Severe corrosion problems are encountered only in those parts of the plant handling aqueous hydrogen fluoride, which since these are limited greatly simplifies the construction problem.

The temperature and pressure of the residual water removal are determined largely by the amount of water which is tolerable in the A.H.F. product. The distillation column operating temperature and pressure can also be varied.

* Nuclear Chemical Plant Ltd., 105 The Broadway, W. Ealing, W.13.

Turbine Contactor Scale-Up

OF interest to designers of agitating machinery is a recent investigation devised to provide scale-up information for turbine contactors carried out by two du Pont de Nemours engineers, D. S. WEBSTER and C. H. WILLIAMSON.*

In greater detail the aim was to discover the pressure developed and the flow capacity of turbine contactors as a function of size and rotational speed, the agitating means consisting of a paddle type stirrer rotating within a shrouded enclosure with discharge vanes. The five rotors investigated had each four vanes, and the shrouded diffusers had 12 blades arranged tangentially at the inner diameter of the shrouds.

Apart from the relationship discussed below Webster and Williamson found that concentricity of rotor and stator had a pronounced effect upon performance, and further, reversal of direction of rotation produced heads and throughputs $\frac{1}{3}$ of those obtained with the correct direction of rotation

The pumping characteristics are represented by a simple relationship between a dimensionless head coefficient ψ, and a dimensionless flow coefficient ϕ. The former is one-half the ratio of measured head to velocity head of the liquid moving at the impeller tip speed, the maximum value of ψ being attained at zero flow. ϕ is the ratio of measured flow to flow calculated from the product of tip speed and peripheral area of impeller. The relation obtained was $\psi = \psi_0 - b\,\phi^2$ where b is a measure of the flow resistance in the unit. In a compromise design ψ_0 is about 0.3 and b is about 7. This gives a further relation Head, in. $= 2.1 \times 10^{-6}\,[(\text{rpm})L]^2 - 2.7 \times 10^{-2}\,[(\text{gpm})/(Lh)]^2$ where L & h are the length and height of the paddle type rotor.

* AEC Research & Development Report DP-506.

Feed-Forward Control Possibilities

THE future of the type of control in which the control action is initiated by input variations rather than by output variations, is one of considerable interest to chemical engineers, particularly as a number of devices have recently appeared which offer this type of action to some degree or other.

Judging from a recent discussion on this subject* neither feed-forward nor feed-back appear to be invariably superior one to the other. It has been suggested that individual unit control by feed-back is important when (a) the controlled system itself offers the cheapest means of analysing inputs and (b) when through considerations of economics or process system characteristics a complex control system is not justified.

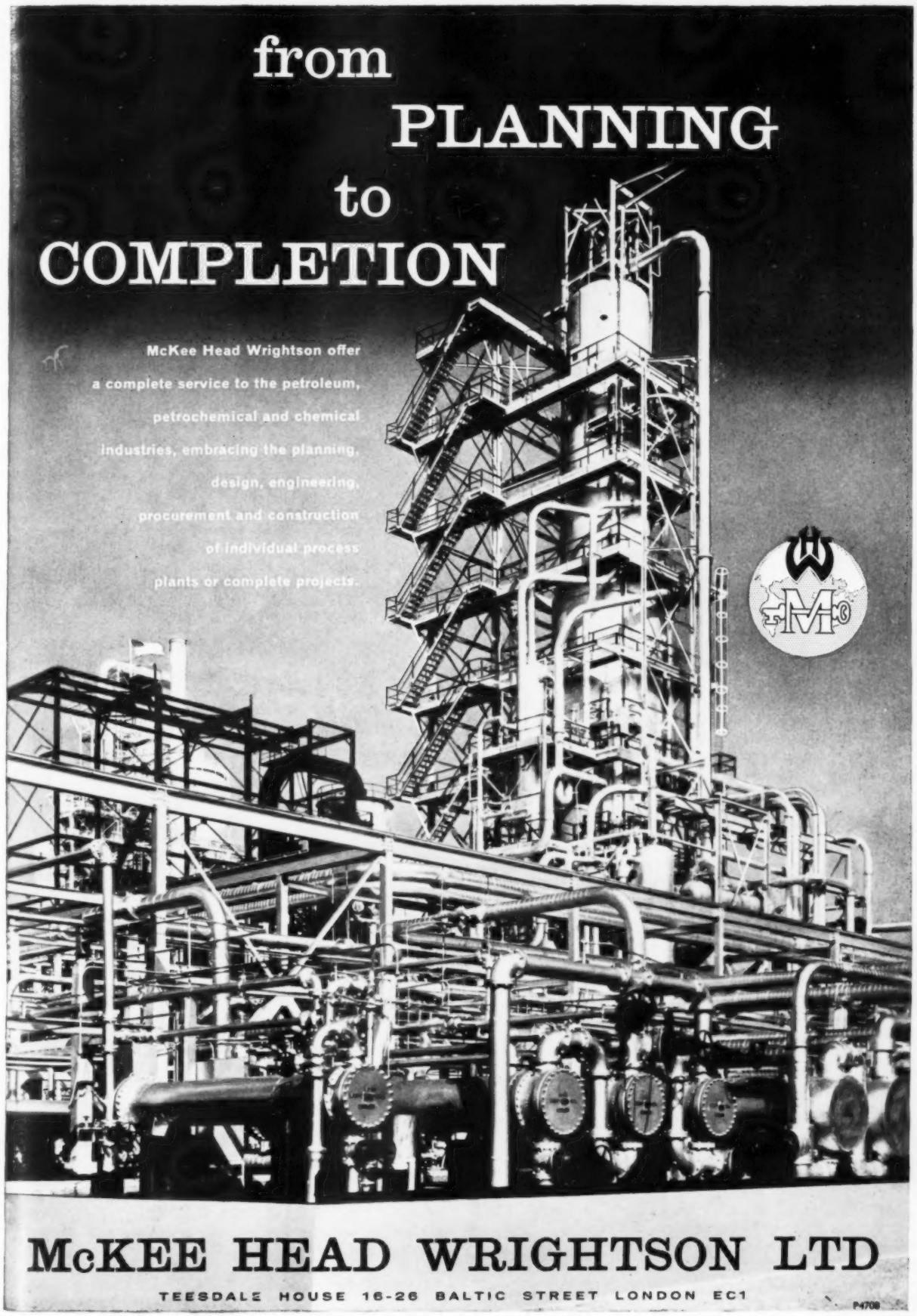
On the other hand the individual unit feed-forward control will be attractive where input information is most economically provided by analytical devices, where feed-back involves marked instability and where continuous computer control (as distinct from optimizing control at discrete intervals) can be justified on economic grounds. Consideration of time delay process shows that feed-back is inadequate, when disturbances have a period less than the process time delay.

One most likely feed-forward development is its combination with what might be termed a feed-back trimmer. The function of such a combination would be to compensate for such changes, which might occur in a process under feed-forward control, through corrosion, fouling and so on, which would require the model of the process to be modified at intervals. The length of such an interval would be unique to a process and would depend upon the process characteristics and the accuracy of the model.

Owing to the limitation of available computing equipment and mathematical theory this model of control is of immediate interest since it will allow us to use linear simulation, which is now well developed, and to up-date the model by coefficient matrix modification.

Philosophically the basic difference between the feed-forward and feed-back is the difference between the scientific and the empirical approaches, for the former implies that we may predict in advance what may happen, and make the adjustments necessary for attaining the desired end, whereas according to the latter we wait to see what happens and then make the adjustments until the required end is obtained.

* Sezmour Calvert and George Coulman in "The future role of feed-forward control in the chemical industry," presented to the Joint Conference on Automatic Control, Boulder, Colo. June 1961.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Removal of Oxides of Sulphur from Flue Gas*

OBJECTIONS have always been made to methods of removing sulphur dioxide from flue gas by washing with water or aqueous solutions on the grounds that the washed gas is cool and moist and drops rapidly to ground level. If therefore the washing process is not very efficient, the concentration of sulphur dioxide near the ground may be greater than if the flue gas had been allowed to disperse by natural buoyancy without washing. Previous investigations at the Laboratory had shown that the use of a dry reagent which did not cool the flue gas would be uneconomic unless a method of regeneration could be developed. A German firm has now discovered a solid absorbent which it is claimed, will work in this way and has agreed to the testing of the method at the Laboratory. Flue gas is passed through the absorbent at 50 to 200°C, when both sulphur dioxide and sulphur trioxide are absorbed. They are subsequently recovered as sulphur dioxide by desorption at above 300°C when the absorbent is regenerated without loss of activity. The process has been found to be quite satisfactory on a laboratory scale, using flue gas from a boiler plant, and larger-scale tests are now being planned.

* From 1960 Annual Report of the Warren Spring Laboratory, Stevenage, Herts.

Translation by Computer

A PRODUCTION system which translates one language into another at 60,000 words per hour by electronic computer was demonstrated in London on September 5, 1961, by Machine Translation, Inc., on an IBM 7090 computer at C.E.I.R. (U.K.) Ltd., in conjunction with the First International Congress on Mechanical Translation.

At the demonstration of the system—called the Unified Transfer System (UTS) invented and developed by MRS. ARIADNE LUKIANOV—an article from the Russian newspaper Pravda was translated into English. Part of this article was also translated into German.

The quality of translation, as shown by a sample translation from Pravda of considerable length, approached that of many commercial manual translations and was quite unambiguous.

The present test production model of the system which has produced the above translation incorporates only 50% of the rules necessary for high quality translation. The remaining rules will be incorporated into the computer programming system during the coming year when the speed of translation will be increased to 150,000 words per hour using the IBM 7090. This UTS will operate on standard computers at a speed which is determined by the computer. With the forthcoming IBM STRETCH computer it may be possible to translate up to 1,000,000 words per hour.

The present general purpose Russian-English dictionary for machine translation contains over 5,000 Russian words and their 32,000 English meanings. A dictionary of 50,000 Russian words and over 300,000 English meanings will be prepared in the coming year. This dictionary should allow translation of non-technical texts excluding poetry and literary art which will never be adequately translated by computer.

For translating scientific texts, it will be necessary to build special technical dictionaries to complement the general purpose dictionary.

The importance of a successful translation system may be gauged from the following facts:

1. Less than 10% of the scientific and technical data from Russia is available to Western scientists.
2. 80% of the professional Russian translators in the U.S. are 60 years of age or older.
3. A skilled person translates only 400 words per hour.
4. Notice of the launching of the first Soviet satellite, including the frequencies of transmission, was published several months before Sputnik was launched. The article was translated several months after the launching, on account of the translator shortage.

In the near future, Machine Translation Inc. hopes to translate Pravda and other Russian newspapers on the same day they are published in Russia. In the not too distant future, MRS. A. LUKIANOV foresees a translation centre in the U.K. which will translate all needed foreign books into English and English material into other languages. Two such centres will cater for the requirements of the United States.

DIARY

Electronic Computer Exhibition

October 3-12 This will be held at Olympia, London, in conjunction with an Electronic Data Processing Symposium.

National Society for Clean Air

October 4-6 The 28th Annual Conference and Exhibition will be held at Brighton.

Council of British Manufacturers of Petroleum Equipment

October 4 The Annual Dinner will be held at The Great Room, Grosvenor House, London, W.1.

Water Pollution Control Federation

October 8-12 The 34th Annual Meeting will be held at the Auditorium, Milwaukee, Wisconsin.

Association of British Chemical Manufacturers

October 11 The Annual Dinner will be held at The Great Room, Grosvenor House, London, W.1.

Society of Instrument Technology

October 11 A Meeting will be held at Mansion House, 26 Portland Place, London, W.1, at which a paper on "Process Control in Paper Mills" will be read.

Institute of Metals

October 16-18 An International Conference on "The Metallurgy of Beryllium" will be held in The Assembly Hall, The Royal Commonwealth Society, Craven Street, London, W.C.2. Registration forms and programme can be obtained from: The Institute of Metals, 17 Belgrave Square, London, S.W.1.

Institution of Chemical Engineers

October 19 The Annual Dinner of the Graduates and Students Section will be held at the Royal Overseas League, Park Place, London, S.W.1, at **7.45 p.m.** Ladies cannot be included among the guests.

Council of British Chemical Plant Manufacturers Association

October 25 The Annual Dinner will be held at Grosvenor House, Park Lane, London, W.1.

First European Symposium on Food Technology

October 26-27 Frankfurt (Main), Germany. Organised as the 34th Meeting of the European Federation of Chemical Engineering. Full details from Institution of Chemical Engineers, 16 Belgrave Square, London, S.W.1.

Institution of Mechanical Engineers

October 30 At this meeting will be discussed "The Extent to which Data can be made available for Engineering Design."
November 2 At this meeting the "Problems of Maintenance in the Petroleum and Kindred Industries" will be discussed. Both meetings will be held at 1 Birdcage Walk, London, S.W.1.

Second Effluent and Water Treatment Exhibition and Convention

October 31-November 3 This will be held at the Seymour Hall, Seymour Place, London, W.1. Registration is £4 per delegate and forms are obtainable from the organisers: Thunderbird Enterprises Ltd., 140 Cromwell Road, London, S.W.7.

SYMPOSIUM ON SCALE-UP AND PILOT STUDIES

EIGHT papers are scheduled to be read at the 1961 Symposium of the Graduates and Students Section of the Institution of Chemical Engineers, which will be held at the Royal Overseas League, St. James's, London, S.W.1, on Thursday 19th and Friday 20th October, 1961.

The first day's proceedings, which will cover four papers on pilot plants, will be presided by PROF. J. F. RICHARDSON.

A pilot plant's capacity is normally 1/10 to 1/100 of the full scale plant; it may cost up to £0.5m and incur correspondingly high operating costs. The decision to build such a pilot plant requires careful thought, and L. HOLLIDAY will open the Symposium with "The case for and against pilot plants."

F. W. B. PORTER will then outline the "Factors affecting the choice of pilot plant size" in a petroleum company when a process is being developed within the company, and when the company proposes to use, on an extensive scale, an established process developed outside the company.

In presenting their paper on "The use of analogue computers in process simulation," P. G. CANDLE and A. D. BOOTH will describe how a computer was used in the development of a new process on a pilot scale to determine whether certain changes to the plant could safely be made which, although otherwise desirable, would cause the reaction system to become inherently unstable.

M. D. WYNNE and G. TURNER will then describe "A general purpose pilot plant" in the final paper of the day.

The second day will be devoted to scaling up of some equipment and processes and the chairman for this session will be PROF. R. EDGEWORTH JOHNSTONE.

M. E. O'KEEFFE TROWBRIDGE will present "The problems in scaling up of centrifugal separation equipment." He will outline the difficulties encountered and the factors which affect scaling up of such units.

In the paper which will follow, W. B. DOBIE will describe how the "Scale-up of rotary vacuum filters" is effected from laboratory measurements with a small leaf filter having about 0.1 sq ft of filter medium.

Methods of scaling up mixer-settlers will be given in "The development of a separation plant for nuclear fuels" by B. F. WARNER. This paper may be illustrated with a demonstration of small-scale mixer-settlers on an exhibition rig.

The Symposium will be concluded with a paper by A. R. COOPER and D. E. CREASEY, on the various aspects of fluidization which determine the "Scale-up in fluidized beds." The present insufficient knowledge of fluidization makes pilot plant development essential for most fluidization applications.

This Symposium promises to be of considerable interest to those who are concerned with the operation of pilot plants, and the interpretation of data for scaling up.

Those wishing to attend should register on a special form which is obtainable from, and which should be returned to, the Institution of Chemical Engineers, 16 Belgrave Square, London, S.W.1, not later than October 12th, 1961. Registration fees include admission to the Symposium on both days, morning coffee and afternoon tea. They are as follows:

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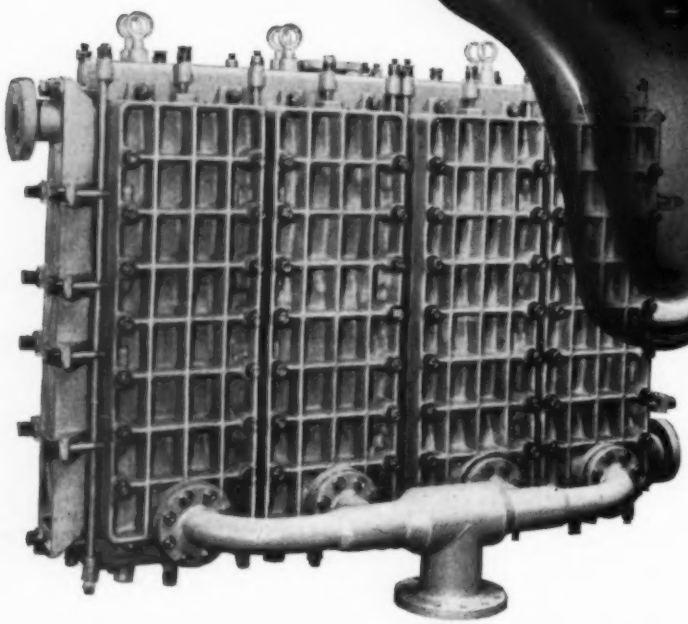

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Chemical Plant Delivery Dates

LATE deliveries of chemical plant and equipment have been the subject of mounting controversy, and a good deal of bitterness, between equipment manufacturers and users, but never has the solution of this problem been so urgent as it is now. With competition in the chemical industry at its peak and with Britain on the threshold of the European Common Market, both the chemical industry and the plant manufacturing industry stand to lose business to continenal firms if the situation is allowed to continue.

Various remedies have been suggested, but most of them are based on an over-simplification of the problem, as viewed from some particular standpoint within the chain of industries concerned, and consequently there is a natural tendency to pass on the blame, rather in the spirit of "everybody is out of step except our Willy". It may be profitable, in order to reach a clearer understanding of the problem, to summarize briefly some of the major elements of discontent within the this chain of industries.

First and foremost, there is the viewpoint of the chemical manufacturer, who forms part of a vigorously expanding industry where competition is extremely keen, and where speed in bringing projects to fruition is vital. Judged simply by the age-old trade dictum that "the customer is always right", the chemical manufacturer rightly expects that his plant requirements will be met promptly, efficiently and sympathetically. His main complaint is that plant suppliers do not keep their delivery promises, and one suspects that plant manufacturers have not expanded capacity to keep pace with increased demand.

For his part, the plant manufacturer feels that chemical manufacturers are often unreasonable in their demands, especially in expecting quick delivery of equipment produced to special designs and incorporating special (and often unnecessary) materials. Another complaint is that often no time is allowed for changes in design introduced after placing the order, while being kept in the dark about the precise conditions in which the equipment will be used is another delaying factor.

The plant manufacturer himself has to contend with late deliveries of forgings and castings, which brings into the picture the foundry industries who, in general, find it difficult to cope with the infinite variety of castings demanded for specialized chemical plant items. They feel that a little more standardization and more attention to forward planning by their customers would be helpful.

These and other facets of the situation were brought to light at the recent Institution of Chemical Engineers discussion, held in Manchester and summarized in *British Chemical Engineering*, 1961, **6**, 627. It is not intended to elaborate on the many grievances and suggestions that emerged from this discussion, but only to note that there appeared to be three main "bones of contention", these being: (1) that there is a need for closer liaison between chemical plant users, contractors and plant suppliers; (2) that more standardization of equipment components is desirable; and (3) that suppliers of stainless steels and other raw materials for plant manufacture could do more to meet the needs of their customers. What can be done, then, to improve the situation?

In the first place, the present high level of plant building activity in the world's chemical industries is stable for some years to come, and plant manufacturers with a backlog of orders would do well to ask themselves whether they have the facilities and manpower to meet the continuing demand. Even where expansion is not necessary, a thorough investigation of the existing structure may reveal ways of streamlining the organization, cutting paperwork and formalities to a minimum when dealing with orders. Delivery dates can perhaps be made more realistic by referring to records of similar items ordered previously, and making due allowance for design work and for possible contingencies such as alterations in design.

Chemical firms might help themselves to obtain quicker deliveries by taking plant suppliers more into their confidence—whether they deal with the suppliers directly or through a contracting firm—and by making initial specifications as precise as possible. Designers should curb the impulse to specify special materials and unusual design features when conventional ones would suffice; here, perhaps, those responsible for the practical training of chemical engineers can exert an influence.

Contractors who are engaged to supervise complete chemical projects are in a unique position in being able to see both sides of the fence at once, and could use their influence with their clients to obtain a sympathetic attitude to the plant suppliers' problems, at the same time urging that as much helpful technical data as possible be released to all concerned with the project, including sub-contractors.

Suppliers of stainless steels and other raw materials for chemical plant manufacture must be shown that it is in their own long-term interest to make every effort to satisfy the needs of the chemical plant industry; no opportunity should be lost of driving this home, either by individual customers or by the trade associations. Far more standardization is also needed, and here again the trade associations can help by issuing propaganda, drawing attention to existing British Standards, and by pointing to the increased economy that standardization can bring.

We have not touched upon the broader issues which confront the chemical plant manufacturer—such as the possible need to operate in larger units in the future, rather in the manner of some contracting firms who have found it profitable to link with others in undertaking certain types of project. The broader issues have a considerable bearing on the plant delivery problem, and a comprehensive approach is necessary to bring about a change in the situation.

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THE ECONOMIC ANALYSIS OF LIQUID-LIQUID EXTRACTION PROCESSES

The detailed cost analysis of a counter-current extraction process is given, and the profit function maximized. The resulting simultaneous alegbraic equations are solved graphically in terms of two-dimensionless cost parameters, the chart being of universal application.
The corresponding analysis for cross-flow operation is also summarized, but the equations are solved analytically with a final step of trial-and-error calculation.
Two examples are given, which indicate that, in general, cross-flow operation is uneconomical, and that about 10 to 15 stages should be used in counter-current operation for the most economical extraction.

by V. G. JENSON and G. V. JEFFREYS

THE economic design and operation of chemical plant is one of the most important functions of the chemical engineer and, therefore, optimization techniques are of great interest to him. This is evidenced by the large number of articles that continue to be published on process economics, particularly those suggesting techniques by which specific unit operations may be optimized. Thus the economic assessment of continuous distillation processes to evaluate optimum reflux ratio, column diameter and number of stages has been thoroughly treated. Also the optimization of heat transfer equipment with respect to fluid velocities and overall temperature difference has been extensively studied. However, very little work has been published on the economics of solvent extraction processes, although ARIS[1] has suggested a procedure based on dynamic programming techniques for the optimization of cross-flow liquid extractions.

No optimizing method has been proposed for counter-current extraction, and therefore the following economic analysis for this type of operation is submitted as a means of estimating the optimum solvent to feed ratio and the number of stages. The corresponding analysis for cross-flow operation is also given briefly, and the two types of operation are compared economically.

For a given feed rate there is an optimum amount of solvent and number of stages which will give the most economical operating conditions for any liquid extraction plant. These conditions depend on many factors such as raw material costs, solvent recovery and make-up costs, capital outlay and the operating costs of the equipment. All of these items must be balanced so that the profit derived from the operation is a maximum, and the purpose of the analysis is to select a suitable solvent to feed ratio and number of stages which will give this maximum. The optimum also depends on which mode of operation is to be employed for contacting the phases, and so counter-current and cross-flow operations must be analysed independently. Since counter-current operation is more frequently used, we will consider it in detail and only quote the corresponding results for cross-flow operation.

DR. JENSON and MR. JEFFREYS are at the Chemical Engineering Department of Birmingham University.

Counter-current Flow Liquid Extraction

Consider a feed solution containing X_0 lb of solute per lb of solute free liquor to be fed to stage 1 of a counter-current extraction process at the rate of C lb/hr on a solute-free basis. Let the process contain N stages, and let an extracting solvent be fed into stage N at the rate of B lb/hr on a solute-free basis. The solvent passes counter-current to the feed liquor through the plant, finally emerging as the final extract from stage 1. The spent feed will be discharged from stage N with a solute concentration X_N. The carrier liquor of the feed will be assumed to be immiscible in the extracting solvent.

It will be further assumed that the feed rate and the solute concentration in the feed are constant and that its value is based on the solute concentration. Thus let the unit cost of the feed in any system of currency be γ per lb of solute, and let α be the total hourly cost of each stage including operation, fixed charges and depreciation of capital. Finally, let the cost of the solvent, including recovery from the final extract and make-up of spillage losses, be β per lb of solvent. Then on the basis of one hour's operation:

$$\text{Cost of feed} = \gamma C X_0 \qquad \ldots . (1)$$

$$\text{Cost of solvent} = \beta B \qquad \ldots . (2)$$

Similarly, if λ is the value of 1.0 lb of extract product, then the total value of the product

$$= \lambda C(X_0 - X_N) \qquad \ldots . (3)$$

and the hourly profit P from the process is:

$$P = \lambda C(X_0 - X_N) - [\alpha N + \beta B + \gamma C X_0] \qquad \ldots . (4)$$

Equation (4) must be solved so that P is a maximum and since the different unit costs will be known, N, B and X_N

are the variables. Of these, X_N is related to X_0 by the equation in MICKLEY[2]:

$$X_N = X_0 \left[\frac{S^{N+1} - S^N}{S^{N+1} - 1}\right] \quad \ldots.(5)$$

where $S = \frac{C}{mB}$ and m is the distribution ratio. Substitution of (5) in (4) gives

$$P = \lambda C X_0 \left[\frac{S^N - 1}{S^{N+1} - 1}\right] - [\gamma C X_0 + \alpha N + \beta B] \quad \ldots.(6)$$

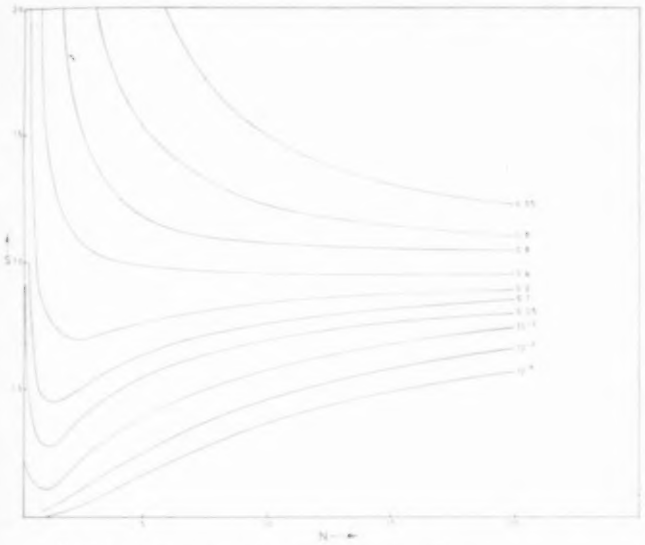
in which the variables are N and B, and it is necessary to find the values of these variables which will make P a maximum. This has been done using the concepts of maximal and minimal surfaces.[2]

Thus differentiating Equation (6) with respect to N gives

$$\frac{\partial P}{\partial N} = \lambda C X_0 S^N \left[\frac{S - 1}{(S^{N+1} - 1)^2}\right] \ln S - \alpha \quad \ldots.(7)$$

Equating to zero and separating the cost terms from the process terms gives:

$$\frac{\alpha}{\lambda C X_0} = \frac{S^N (S - 1) \ln S}{(S^{N+1} - 1)^2} \quad \ldots.(8)$$



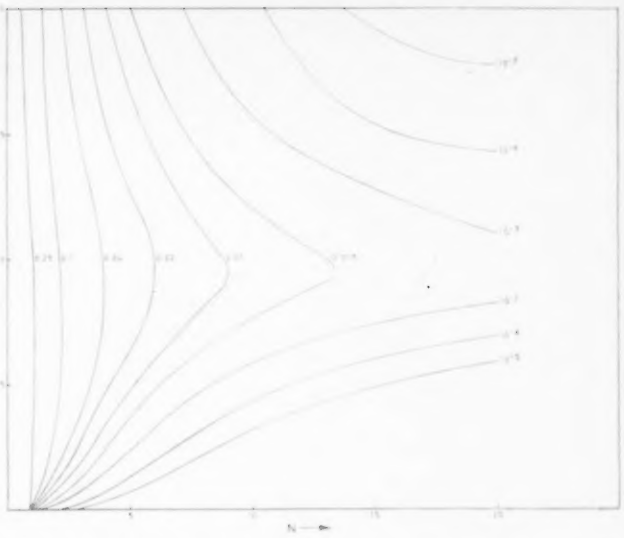
▲ *Fig. 1. Contour chart of Equation* (8).

Similarly, differentiating Equation (6) with respect to B, equating to zero and separating cost and process terms gives:

$$\frac{\beta}{\lambda m X_0} = \frac{S^{N+1} (S^{N+1} + N - NS - S)}{(S^{N+1} - 1)^2} \quad \ldots.(9)$$

Equations (8) and (9) are two complex simultaneous equations that will be difficult to solve analytically, but since N is a whole number, an approximate but sufficiently accurate solution has been obtained graphically by the following procedure.

For any pair of values of S and N, the right-hand sides of Equations (8) and (9) can be evaluated, giving a numerical value for each of the dimensionless cost groups $\frac{\alpha}{\lambda C X_0}$ and $\frac{\beta}{\lambda m X_0}$. Thus by taking a series of pairs of values for S and N and repeating the calculations, a contour chart can be drawn for each cost group using S as ordinate and N as abscissa. These calculations were performed for all integer values of N from 0 to 15 plus the value 20, and values of S at intervals of 0.1 from 0 to 1.0, and intervals of 0.25 from 1.0 to 2.0. A few extra points were calculated near the origin and near the S axis, and Fig. 1 shows the contour chart for Equation (8) and Fig. 2 illustrates Equation (9).

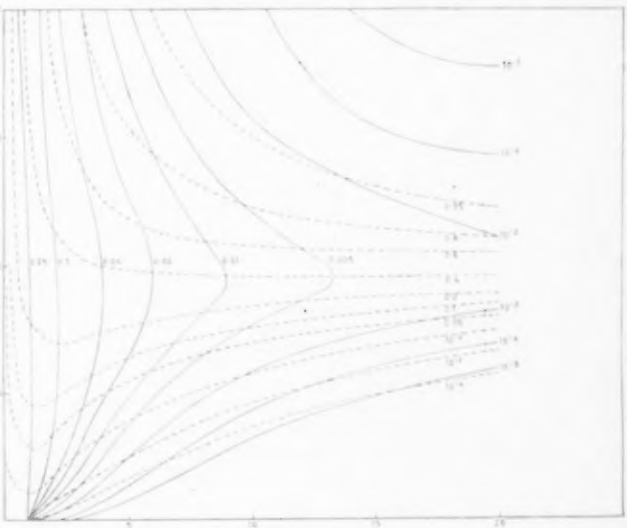


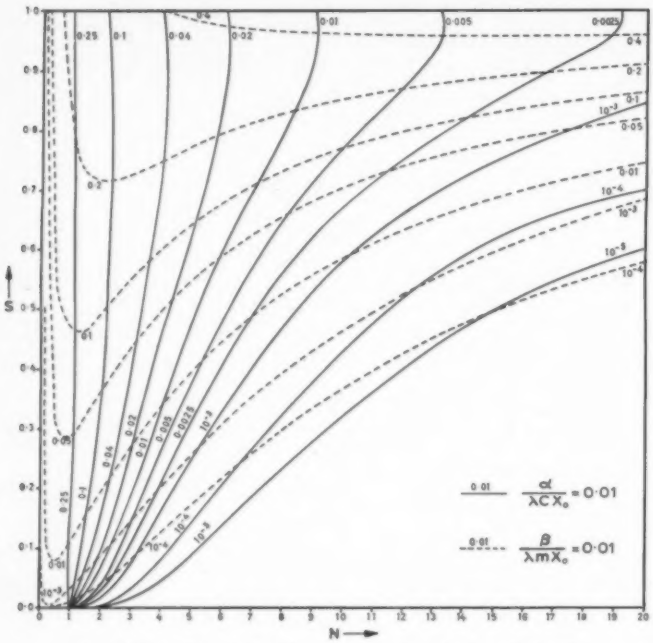
▲ *Fig. 2. Contour chart of Equation* (9).

In a particular example, the basic cost terms would be known, enabling the cost groups to be evaluated. For these values, Equation (8) is satisfied along one curve in Fig. 1 and Equation (9) is satisfied along a curve in Fig. 2. Both equations can only be satisfied simultaneously at the point of intersection of these two chosen curves. This point can easily be located by superimposing the two contour charts as shown in Fig. 3, and the co-ordinates of the point of intersection give the modified solvent to feed ratio and the number of stages for optimum operation.

It is thought that the useful range of this combined chart will be $0 \leq S \leq 1.0$ and $0 \leq N \leq 20$, and since this chart is universally applicable to counter-current extraction processes (provided that the solvents are immiscible or nearly so), Fig. 4 has been prepared as an accurate version of Fig. 3 for this range.

▼ *Fig. 3. Graphical solution of Equations* (8) *and* (9).





▲ *Fig. 4. Generalized solvent extraction optimization chart.*

Cross-flow Extraction

A similar economic analysis to that given above, but based on equal quantities of solvent being fed to each stage of the cross-flow process, would result in the following pair of simultaneous equations:

$$\frac{\alpha + \beta B}{\lambda C X_0} = \left(\frac{S}{S+1}\right)^N \ln\left(\frac{S+1}{S}\right) \quad \ldots\ldots(10)$$

$$\frac{\beta}{\lambda m X_0} = \left(\frac{S}{S+1}\right)^{N+1} \quad \ldots\ldots(11)$$

These could be solved using the same graphical technique as before, using the same two dimensionless cost groups and a different range of values for S, but it is possible to eliminate S algebraically and obtain the equation

$$1 - \frac{\alpha m}{C\beta} = \left(\frac{\beta}{\lambda m X_0}\right)^{-p} \left[1 + p \ln\left(\frac{\beta}{\lambda m X_0}\right)\right] \quad \ldots\ldots(12)$$

where $p = 1/(N+1)$.

This can be solved by trial and error for p and hence N, and Equation (11) can then be used to determine S. Equation (11) is the correct equation to use, since it is the condition for the profit to be a maximum with respect to S for fixed N, and the value used for N is only approximate, since it must be an integer.

Example 1

8000 lb/hr of a 5 per cent by weight solution of acetaldehyde in toluene is to be treated with water to extract the acetaldehyde. If the annual capital and operating costs per stage are estimated to be £1600, the cost of supplying, pumping and regenerating the solvent from the final extract is estimated to be £4.5 per ton, and the value of the acetaldehyde is taken to be £155 per ton; what is the optimum number of stages and quantity of solvent required for the process? The distribution ratio is 2.2, and the operating time is 8000 hr per annum.

5 per cent solution gives $X_0 = 0.053$

$CX_0 = 400$ lb/hr;
$\alpha = 4$s. per hr;
$\beta = 0.0402$s. per lb;
$\lambda = 1.384$s. per lb

$$\therefore \frac{\alpha}{\lambda C X_0} = 0.0072, \quad \frac{\beta}{\lambda m X_0} = 0.251$$

From Fig. 4, $N = 10$ or 11 stages, $S = 0.90$

$\therefore B = 3840$ lb/hr solvent.

With $S = 0.90$, the profit is as follows:

N	*Profit*	*Fraction Extracted*
12	334.0-400γ	0.962
11	334.7-400γ	0.956
10	334.8-400γ	0.949
9	333.9-400γ	0.941
5	312.8-400γ	0.874

For cross flow: from Equation (12)

$0.9713 = (3.984)^p\ (1 - 1.3823p)$

If $N = 5$, R.H.S. = 0.9690

If $N = 6$, R.H.S. = 0.9777

$\therefore N = 5$ is the optimum number of stages

$\therefore S = 3.86$

$\therefore$ Profit $= 180.7 - 400\gamma$

$\therefore$ Total solvent used = 4490 lb/hr

Fraction extracted = 0.684

Example 2

1000 ft³/hr of an aqueous liquor containing 5 lb of diethylamine per ft³ of solution is to be treated with toluene to extract the diethylamine. Estimate the optimum number of stages and the quantity of solvent required if the capital and operating cost of each stage, including vessels, pumps and labour, is estimated to be $7000 per annum. The cost of regenerating, recycling and adding make-up solvent is estimated to be $0.015 per ft³ of solvent, and the value of the diethylamine is estimated to be $0.53 per lb. The plant is to operate for 8000 hr per annum, and the distribution ratio of diethylamine between toluene and water is 0.86.

$X_0 = 5$ lb/ft³;
$CX_0 = 5000$ lb/hr;
$\alpha = 0.875$ $/hr;
$\beta = 0.015$ $/ft³;
$\lambda = 0.53$ $/lb

$$\therefore \frac{\alpha}{\lambda C X_0} = 3.3 \times 10^{-4}, \quad \frac{\beta}{\lambda m X_0} = 6.6 \times 10^{-3}$$

From Fig. 4, $N = 15$ stages, $S = 0.67$

$\therefore B = 1740$ ft³/hr solvent.

With $S = 0.67$, the profit is as follows:

N	*Profit*	*Fraction Extracted*
16	2608.5-5000γ	0.9995
15	2608.6-5000γ	0.9992
14	2608.4-5000γ	0.9988
10	2599.0-5000γ	0.9939
5	2489.7-5000γ	0.9510

For cross flow: from Equation (12)

$0.9498 = (151.9)^p\ (1 - 5.0232p)$

If $N = 16$, R.H.S. = 0.9467

If $N = 17$, R.H.S. = 0.9530

$\therefore N = 16$ is the optimum number of stages.

$\therefore S = 2.909$

$\therefore$ Profit $= 2516.5 - 5000\gamma$

$\therefore$ Total solvent used = 6400 ft³/hr

Fraction extracted = 0.9911

Discussion

The cost data for the first example were obtained from a variety of sources, but the data for the second example is all taken from *Chemical Plant Design*, by VILBRANDT and DRYDEN.

In both examples, the final profit figures contain the quantity γ, which will be difficult to determine since the feed

stream to this unit operation will be an internal stream of a larger process. The material to be extracted could be either the main product of a plant, or just a valuable by-product, and in either case its value is rather arbitrary. Since γ does not affect the optimum operating conditions, it is not essential to have a numerical value for it, but the profit figures have to be compared as an increase or decrease of profit which cannot be expressed as a percentage.

A comparison between counter-current and cross-flow operation shows that counter-current operation is to be preferred, although the reasons are different in the two examples given. In the first example, the profit will be increased by more than 85 per cent (depending on γ) by using counter-current flow, and further advantages are that the extraction is much nearer completion and slightly less solvent is required. The chief advantage of counter-current operation in the second example is that only about a quarter of the amount of solvent is required to give the same degree of extraction in a comparable number of stages. The profit still shows a useful increase of $92 per hour, or about $750,000 per annum.

For both examples, the profit function has been evaluated for different numbers of stages in counter-current flow to show that the optimum number determined by reference to Fig 4 is in fact an optimum. These tables also show that it is not vital to have the exact optimum number of stages, but that the profit falls considerably if the number of stages is reduced by more than 25 per cent.

Both examples suggest that solvent extraction processes should be operated with more stages than have hitherto been used, since the extra capital cost can be justified economically by improved extraction. The disadvantages of a large number of stages are that more material is held up in the system, and the start-up time is increased. The first disadvantage can be considered to be a small increased capital cost, whereas the second is only applicable to initial start-up with empty tanks, and during normal operation the tanks would be left full while the plant is shut down.

Conclusions

The graphical solution of simultaneous equations is not normally very useful since separate charts have to be prepared for each example, whereas in the case of solvent extraction, Fig. 4 is of universal application. This is due to the cost terms and process terms being separable in Equations (8) and (9). The cost parameters $\frac{\alpha}{\lambda C X_0}$ and $\frac{\beta}{\lambda m X_0}$ are both dimensionless, and examples can be solved in any consistent system of units as shown by the two examples given.

Finally, it is shown that cross-flow is not a commercial proposition unless some special circumstances relating to adjacent unit processes exist in a particular manufacturing operation.

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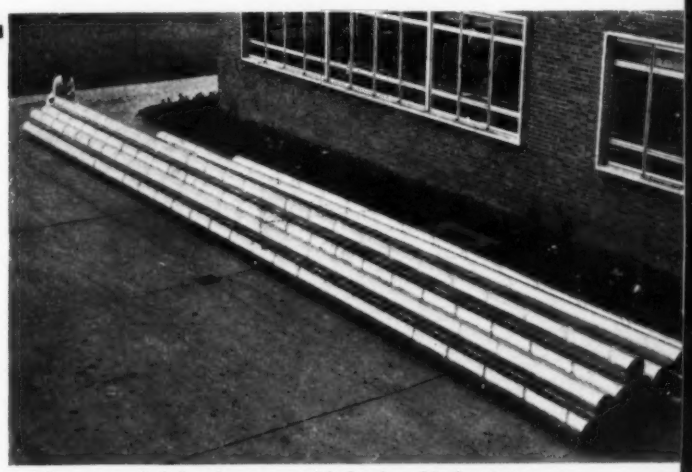
Helical-Weld Aluminium Pipe



The successful development of helical-weld aluminium pipe makes possible large-diameter thin-wall pipes such as these. (Courtesy Alcan Industries Ltd.)

LARGE-SCALE production of aluminium pipe in sizes up to 28-in. diameter is now possible due to the successful adaptation of the helical-weld method of tube making to aluminium. The two main types of aluminium tubing that were until now available in large quantities, extruded and drawn seamless tubing, have been limited by practical considerations to a maximum diameter of approximately 12 in. The method sometimes used to fabricate large-diameter pipes —bending plates into cylindrical shapes and welding them longitudinally—does not lend itself to large-scale production.

The method of making helical-weld tube consists essentially of feeding metal strip into a series of rollers set at an angle so that the strip describes a helix as it travels through the machine. This helical seam is then continuously and automatically welded, and the tubing can be made in very long lengths to accurate limits.

The process was first developed for steel pipe at the end of the last century, but it took many years of improvements in strip quality, in automatic welding techniques, and particularly in continuous weld testing and quality control, before the production of consistently high-quality helical-weld pipe became a practical proposition. Now welding is faster with aluminium than with steel, and the high speeds possible lead to high output rates and low manufacturing costs.

Helical-weld aluminium pipe was developed by Alcan Industries (then Northern Aluminium) in collaboration with makers and operators of helical-weld equipment. It is now offered in sizes from 6 in. to 28 in. diameter with wall thicknesses up to $\frac{1}{4}$ in. by three British companies: Apitubes Ltd., Bristol Aerojet Ltd. and The British Steel Piling Co. Ltd. Apitubes are producing pipe on helical-weld equipment designed and built at their Jarrow-on-Tyne works; Bristol Aerojet Ltd. have developed a different type of machine which produces helical-weld tube to exceptionally close tolerances for the more specialized types of application; and The British Steel Piling Co. Ltd. are operating a "Driam" helical-weld machine at their Claydon Works, near Ipswich.

On the Continent, Intercontinental Enterprises G.m.b.H. are building their "Heliweld" plant at Oberhaussen, near Düsseldorf. This equipment is capable of forming tube up to 120 in. diameter from strip up to $\frac{1}{2}$ in. thick; it can therefore be used for making cylindrical vessels and tanks as well as tubing.

66.04:536:532.5

A HYDRAULIC ANALOGUE FOR TRANSIENT HEAT TRANSFER PROBLEMS

by CARLOS DUHNE

A high-precision hydraulic analogue computer is described, together with details of its use for the solution of several simple problems. The quantitative interpretation of the results obtained is discussed. The form of solution of more complicated problems is mentioned. The precision of a simple set-up was found to be 0.476 mean deviation, 1.20 per cent the maximum deviation.
The use of dimensional analysis simplifies the interpretation of results, and a dynamic calibration method is presented, which improved the accuracy of the results obtained.
The computer, in addition to solving transient heat-transfer problems such as occur in regenerator design, whose corresponding differential equations are difficult or impossible to solve, can also be used for diffusional problems.

Introduction

WHEN a body is heated or cooled, the temperature of any point can be obtained by solving the differential equation:

$$\frac{\partial t}{\partial \theta} = \alpha \left(\frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} + \frac{\partial^2 t}{\partial z^2} \right) \qquad \ldots . (1)$$

x, y, z are distances in directions at right angles one to another.
t = temperature; θ = time.

Unfortunately, in many cases the solution is rather complex, and graphic methods[5, 6, 7] or analogue computing machines[5, 6, 7, 8] have been used to obtain the solutions.

At the Instituto Tecnológico de Monterrey a hydraulic analogue computing machine was built for instruction and research purposes.

As will be seen later, the instruction value of the machine is high, because changes in temperature, represented by level in a series of vertical glass tubes, can be seen to vary in a very objective manner.

The machine consists of a series of capillary tubings and vertical tubes, called standpipes from now on, connected in series as shown in Fig. 1.

Water flows from a constant level tank to a series of capillary tubes, with a standpipe connected at the end of each capillary. If the level of the water in the standpipes is maintained constant initially (such as $A\ A'$ in Fig. 1) and the valve suddenly opened, liquid will flow through the capillaries, and the level in the burettes will slowly rise.

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The analogy between heated body and the hydraulic model is apparent from the following facts:

(1) In both cases there is a resistance to flow—in one case heat flow; in the other, liquid flow.
(2) In both cases there is storage—in one case heat is storaged as the body increases its temperature; in the other, the liquid in the standpipes.
(3) In the both cases there is a gradient of the variable causing the flow—in one case temperature; in the other liquid level (or pressure).
(4) In both cases the flow is proportional to the gradient of the appropriate variable.

The principal difference is that one system is continuous and the other is by steps. Clearly, the model has to be built of many elements if a true resemblance is to be approximated.

The similarity will be even clearer when the differential equations applicable in both cases are compared.

Theoretical Considerations

The flow in the capillary tubing produces a pressure drop according to the Poiseuille equation:

$$dP_c = \rho dh = \frac{32\ \mu\ V_c\ dx}{g\ D_c^2} \qquad \ldots . (2)$$

where P_c = pressure drop in the capillaries;
ρ = density;
h = difference in hydrostatic pressure in length units.
μ = viscosity;
V_c = velocity;
x = distance;

g = gravity constant;
D_c = capillary diameter.

Substituting the velocity (V_c) for the volumetric flow (Q_c) between the cross-section of the capillary (A_c):

$$V_c = Q_c / A_c \qquad \ldots.(3)$$

and eliminating Q_c:

$$Q_c = \left(\frac{\pi \rho g D_c^4}{128 \mu}\right) \frac{dh}{dx} = \frac{1}{\oint} \frac{dh}{dx} \qquad \ldots.(4)$$

where Q_c = volumetric flow (volume/unit time);
$\oint$ = a constant.

Where $\oint$ is a constant for a given capillary-fluid system:

$$\oint = 128 \mu / \pi \rho g D_c^4$$

Differentiating Equation (4) with respect to distance x, we have:

$$\frac{dQ_c}{dx} = \frac{1}{\oint} \frac{\partial^2 h}{\partial x^2} \qquad \ldots.(5)$$

$$\text{Let } S = \frac{\text{Standpipe cross-section}}{\text{capillary length}}$$

By a material balance, considering that the liquid accumulation in the time increment, $\Delta\theta$, is equal to the difference between the flow leaving and entering a length of tube (Δx):

$$\Delta h (S \Delta x) = Q_2 \Delta\theta - Q_1 \Delta\theta = \Delta Q \,.\, \Delta\theta \qquad \ldots.(6)$$

This equation can be put in the form:

$$\frac{\Delta Q_c}{\Delta x} = S \frac{\Delta h}{\Delta x} \qquad \ldots.(6)$$

If the model is built with many capillaries and standpipes,

$$\frac{\Delta Q_c}{\Delta x} = \frac{dQ_c}{dx} \qquad \ldots.(7)$$

and

$$\frac{\Delta h}{\Delta x} = \frac{dh}{dx} \qquad \ldots.(8)$$

so that

$$\frac{dQ_c}{dx} = S \frac{dh}{dx} \qquad \ldots.(9)$$

Equations (5) and (9) given:

$$\frac{dh}{d\theta} = \frac{1}{S \oint} \frac{d^2 h}{dx^2} = \alpha' \frac{d^2 h}{dx^2} \qquad \ldots.(10)$$

Now let an infinite slab be considered, being heated or cooled from the infinite surfaces. Heat will flow only in one direction, perpendicularly to the surfaces, and Equation (1) reduces to:

$$\frac{dt}{d\theta} = \alpha \left(\frac{\partial^2 t}{\partial x^2}\right) \qquad \ldots.(11)$$

The similarity of Equations (10) and (11) is evident. The analogy between temperature and the level of the liquid in the standpipes is also evident.

Experimental Equipment

The *standpipes* were made of high precision burette tubes, (Ultramax, made by Fisher & Porter Co.), of 0.000900 sq ft cross-section.

The *capillary tubing* was made of standard pyrex capillary tubing, 1 mm approximately. The desired length was cut, and a number of such tubes were compared as described later. Only tubes with a ± 0.55 per cent maximum resistance difference were selected.

Originally the glass tubes were heated and expanded in both ends, but investigation of the results obtained showed this to be unnecessary. It was necessary to polish both ends so that the resistance of a liquid flowing in both directions is kept constant. It was found that the minimum capillary length to diameter ratio should be 80 to 1, so that the pressure drop is proportional to the flow rate with a 5-cm water pressure differential. At lower ratio or higher pressure drops between each capillary tube, a direct proportionality does not exist because of turbulence in the expansions and contractions at the ends of the capillaries.

Constant level tanks. Two of the three provided were connected with a three-way glass valve to the first capillary and the third tank was connected to the last capillary.

Liquid used was water, with a very small amount of a red dye to assist in photographing the liquid levels. Copper sulphate was used to prevent algæ formation.

Photographic equipment was a Rolleicord, Plus X film, the exposure 1/50, f:11, and illumination was provided by a translucent glass panel fitted behind the standpipes. The panel itself was illuminated by eight fluorescent lights.

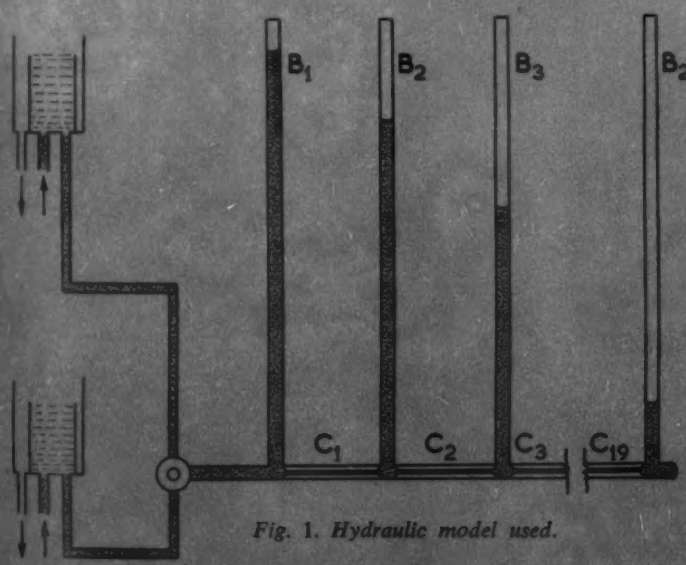


Fig. 1. Hydraulic model used.

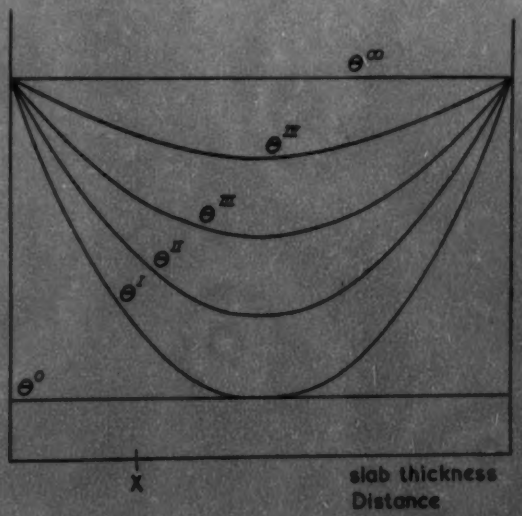


Fig. 2. Temperature distribution in a slab heated from both faces, at different times θ.

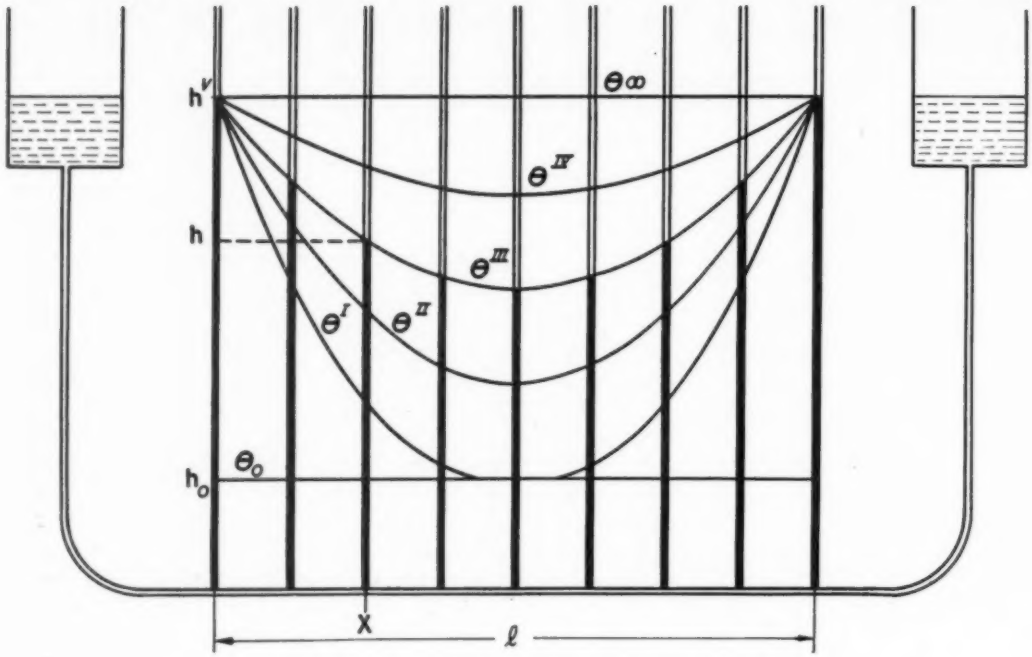


Fig. 3. Liquid distribution curves at different times θ.

Electric watch with a big second hand was provided so that the photograph would register the exact moment when it was taken.

A liquid recirculating pump to recirculate water and maintain a constant level.

The calibrating rig consists of a line connected to a constant level tank in which the flow resistance of two capillary tubes is compared by measuring the pressure drop. One is the comparison standard, the other the capillary tested.

Interpretation of the Results Obtained in the Model in a Simple Case

Let an infinite slab originally at a uniform temperature t_0 be considered. The temperature of the surfaces is then raised to t'. At times θ_0, θ', θ'', the temperatures will be given by the curves of Fig. 2.

In the model, initially all standpipes are at a low level, h_0, and then suddenly connection is made at each end to a constant level tank at high level, h'. A series of level curves (h) is then obtained, at times θ_0, θ', θ'', θ''', etc. (Fig. 3).

In order to use the charts, as an example take the first and substitute the original variables for the following parameters, (Fig. 4).

$\frac{t-t_0}{t'-t_0}$ is the new temperature scale; the time values in the curves are substituted by the corresponding values of the dimensionless group, $4\alpha\theta/l^2$, and finally the distances are substituted by the dimensionless groups (x/l). This process is repeated in the second graph (Fig. 5).

$\frac{h-h_0}{h'-h_0}$ has been used instead of h, and x'/l' is substituted for distance.

In view of the analogy, the values of $4\alpha\theta/l^2$ in both figures must coincide. If the equivalent value of α for the model is known, then the values of $4\alpha\theta/l^2$ can be calculated.

Now by methods of dimensional analysis, it can be shown that for a different system, with different α and l values, the same graph will apply and the curves will be identical; the only difference will be that the values of $4\alpha\theta/l^2$ will be obtained at time values differing from those of the model.

In practice it is enough to build half the model, because the curves obtained are symmetrical and, in addition, the slope of the curves is always zero at the centre of the slab, and thus there will be no flow in the centre.

1. *Determination of the apparatus constants.* In Equation (10) the constants S and $\oint$ have to be evaluated, so that the equivalent $\alpha' = 1/S\oint$ can be determined. One method would be to use the equation

$$\oint = \frac{128\,\mu}{\pi\, g\, \rho\, D_c^4}$$

The difficulty in applying this equation is that a small error in the capillary diameter determination will produce a big error in the constant $\oint$. The diameter might change somewhat, and the entrance and exit losses would not be correctly determined.

It is better to find the values of constant $\oint$ by dynamic transient method. This consists of:

1. Arranging the apparatus in a simple manner corresponding to problems allowing an easy solution of Equation (1) by the methods of Calculus.

2. Comparing the result obtained by the model in a time θ, with the solution of the Equation (1).

Consider the same case of a slab being heated. In this simple case the solution of Equation (1) is:

$$\frac{t_0-t}{t_0-t'} = \frac{4}{\pi}\left(e^{-a_1 X}\sin\frac{\pi x}{2r_m} + \frac{1}{3}e^{-9a_1 X}\sin\frac{3\pi x}{2r_m} + \frac{1}{5}e^{-25a_1 X}\sin\frac{5\pi x}{2r_m} + \ldots\right) \quad \ldots(12)$$

where $X = \frac{\alpha\theta}{r_m^2}$; $a_1 = \left(\frac{\pi}{2}\right)^2$;

r_m = distance, centre of slab to free surface;
x = distance, centre of slab to point considered.

The experiment is prepared by allowing all standpipes to have the same level, h_0. Then the valve is opened and water from the constant level tank begins to flow. After some time

has elapsed, the level in the last standpipe is measured. From the level data and the time elapsed the value of α' is obtained from Equations (10) and (11).

In other words, in this way the thermal diffusivity α' of an imaginary slab is obtained, in which for the same time interval the curves of $(t - t_0)/(t' - t_0)$ and $(h - h_0)/(h' - h_0)$ against x/l would be identical. The thickness of the slab would be the length of all the capillary tubes. From the α value the value of $\oint$ can be obtained.

The variation of the constant with temperature has to be considered; according to Equation (5), $\oint$ is proportional to viscosity. A simple correction would be to obtain the new $\oint$ value by merely correcting for the viscosity changes. A more exact way, one which takes into account end effects, is to obtain the value of $\oint$ directly at different temperatures.

To place the capillaries in a constant temperature bath is not an adequate measure because water flows from the constant level tank at a different temperature. Also, a difference in temperature between the standpipes and the liquid in the capillaries requires a correction for the density change; between 15°C and 33°C the difference is 0.44 per cent. Neither is it correct to assume that the water in the standpipes is at room temperature, and the temperature cannot be measured without changing the levels in the standpipes. Because of these difficulties the best course was to operate at room temperatures, and to introduce the corresponding viscosity correction.

So that the differences in resistance of the capillaries would tend to cancel each other, they were connected in series; first that with the highest constant with the lowest, then the second largest with the second lowest, and so on.

By means of these refinements it was possible to obtain a mean deviation of 0.47 per cent and a maximum deviation of ±1.20 per cent of experimental values compared with the mathematical solution.

Infinite Slab with Film Resistance

The next case in order of complication is an infinite slab, with a film resistance. This can be simulated in the model by a capillary tubing of suitable length connected before the first standpipe. The necessary length for the representation of a given film resistance (l/h) can be calculated as follows:

Consider the case of steady conduction of a fluid to a solid. The film resistance can be considered to be equivalent to the resistance of a slab x ft thick, of the same material as the body, so that:

$$q = h\,A\,\Delta t = k\,A\,\Delta t/x \qquad \ldots.(13)$$

where q = heat flow (heat/unit time);
h = film coefficient;
A = area;
Δt = temperature difference;
x = width of the slab.

Thus: $$h = k/x; \text{ or } hx/k = 1 \qquad \ldots.(14)$$

Multiplying and dividing by the slab thickness L, we have:

$$\left(\frac{hL}{k}\right)\left(\frac{x}{L}\right) = 1 \qquad \ldots.(15)$$

In changing from the conditions of the slab to the condition of the model, a change in the time units is usually introduced, but the value of the dimensionless groups is kept constant; hence:

$$\left(\frac{hL}{k}\right)\left(\frac{x'}{L'}\right) = 1 \qquad \ldots.(16)$$

or

$$x' = L'\left(\frac{k}{hL}\right) \qquad \ldots.(16)$$

where x' is the length of capillary tubing equivalent to the film resistance h, and L' is the length of all the capillaries representing the slab. If one uses the half-model, the actual capillary length should be doubled. The interpretation is now the same as for the slab without a film resistance.

Suppose that the problem is to find at a certain time the temperature at a given point in an infinite slab.

Given the properties of the slab, the value of $\alpha = k/\rho C_p$ can be found, and from it the value of $4\alpha\theta/L^2$. For this model the same value of $4\alpha'\theta'/L^2$ will be obtained, and, knowing the value of α' and L', the new time θ' is obtained. This is time by the model that is equivalent of θ in the slab.

Now, after assembling the capillaries corresponding to this case, and allowing time θ' to elapse, the value of the liquid in the standpipe is measured and the temperature at the corresponding point is calculated from the formula:

$$\frac{t - t_0}{t' - t_0} = \frac{h - h_0}{h' - h_0} \qquad \ldots.(17)$$

Fig. 4. Temperature distribution on a slab, as function of $\frac{4\alpha\theta}{l^2}$ parameter.

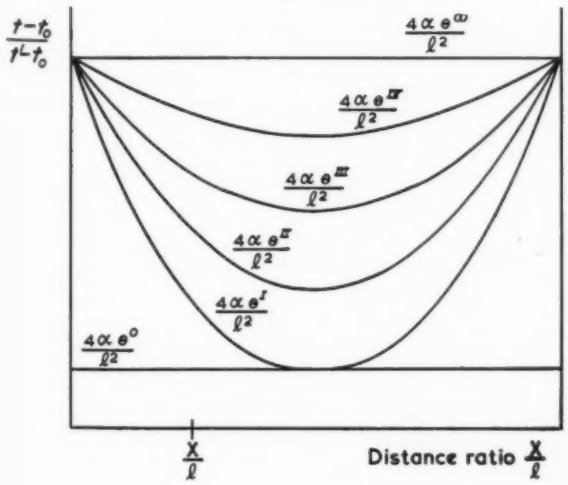
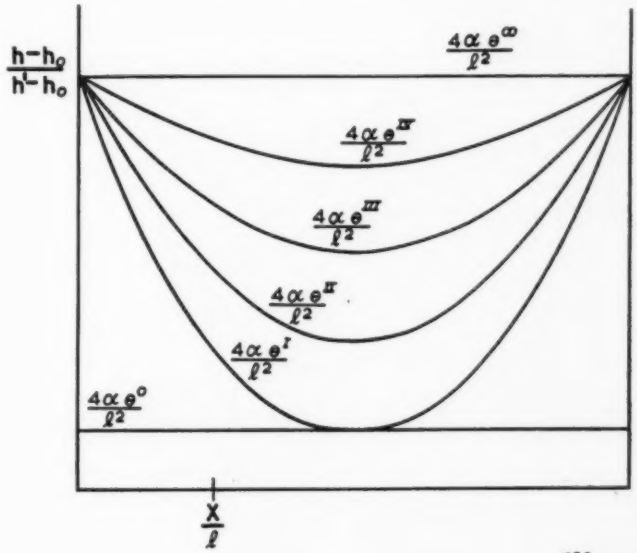


Fig. 5. Level distribution parameter as a function of the time parameter.



Two-joint Infinite Slabs

In this case $\frac{4\alpha_1'\theta}{L_1^2}$ for one slab and $\frac{4\alpha_2\theta}{L_2^2}$ for the other, are different. In our model, the corresponding values of $4\alpha_1'\theta'/L_1'^2$ and $4\alpha_2'\theta'/L_2'^2$ will be equal to the corresponding value in the slabs.

$$\frac{4\alpha_2'\theta'}{L_2'^2} = \frac{4\alpha_1'\theta'}{L_1'^2}\left\{\frac{\left(\frac{4\alpha_2\theta}{L_2^2}\right)}{\left(\frac{4\alpha_1\theta}{L_1^2}\right)}\right\} \qquad \ldots.(18)$$

Remembering that $\alpha_2' = \frac{1}{S_2 f_2}$

and $f_2 = \frac{128\mu}{\pi\rho g D_c^4}$

If the model is to use the same capillary tube diameter, but of different lengths, the changes in α' will be due to changes in the values of S, f_2 being constant.

The corresponding times in the two parts in the model are also constant. Therefore, Equation (18) simplifies to:

$$\frac{1}{S_2 L_2'^2} = \frac{1}{S_1 L_1'^2}\frac{\left(\frac{4\alpha_2\theta}{L_2^2}\right)}{\left(\frac{4\alpha_1\theta}{L_1^2}\right)} \qquad \ldots.(19)$$

S is the area of standpipe between the length of the capillary, so that:

$$S_2 = \frac{n_2 A_2}{L'_2} \qquad \ldots.(20)$$

where n_2 is the number of standpipes in slab No. 2, A_2 is the cross-section of standpipe and L'_2 the total capillary length, in slab No. 2.

$$\therefore \quad \frac{1}{n_2 A_2 L'_2} = \frac{1}{n_1 A_1 L_1}\frac{\left(\frac{4\alpha_2\theta}{L_2^2}\right)}{\left(\frac{4\alpha_1\theta}{L_1^2}\right)} \qquad \ldots.(21)$$

If we use the same standpipe cross-section for both slabs, models ($A_1 = A_2$) then it follows that

$$n_2 L_2' = n_1 L_1'\frac{\left(\frac{4\alpha_1\theta}{L_1^2}\right)}{\left(\frac{4\alpha_2\theta}{L_2^2}\right)} \qquad \ldots.(22)$$

Take a simple composite slab problem, with film coefficients h_1 and h_2, and let the body initially at the same uniform temperature, t_0, be suddenly subjected to a temperature t' on the free side of slab No. 1. Required: a temperature plot against the distance at a time θ. The temperature will continue to be t_0 at the other side of the wall.

Model Construction:

1. Model of slab No. 1 is constructed arbitrarily (e.g., 10 capillary tubes, 15 cm in length).

2. The value of $n_2L'_2$ is found from Equation (21) and the number of standpipes (N_2) and the length of each of them is selected. The selection is somewhat arbitrary and any combination that gives the same value of n_2L_2 will give the same result.

3. To take in consideration the film resistance h_1, a capillary of length

$$x_1' = L_1'\left(\frac{k_1}{h_1 L_1}\right)$$

is put before the set of capillaries representing slab No. 1.

4. A capillary length of

$$x_2' = L_2'\left(\frac{k_2}{h_2 L_2}\right)$$

is put after the last capillary representing slab No. 2. A constant level tank at a high h_1 is connected through a valve to the first capillary and a constant level tank, at high level h_0, is connected to the last capillary.

Interpretation of Results

After allowing all capillaries to reach a same level h_0, the valve of the constant level tank at h_1 is opened and after a time θ' has elapsed a photograph is taken.

When this has been developed a graph is constructed using the projection of the photograph. From this graph, the value of the temperatures is calculated from

$$\frac{h-h_0}{h_1-h_0} = \frac{t-t_0}{t_1-t_0}$$

Other problems that can be solved by the computer, apart from those considered above, are those of the infinite slab, single or composite, but with different operation conditions. As an example, work is being carried out in the I.T.E.S.M. on a more complete set of curves than those at present available, upon a Gurnie-Lurie type chart for the case of the infinite slab heated either at both sides, or at a single side (e.g., the wall of a furnace being heated).

Two-dimensional and three-dimensional models can be constructed. For the flow of heat to an infinite cylinder or a sphere, the body is hypotheticaly divided in segments of equal volumes, and the capillary length is calculated for each of the segments.

For three dimensional flow NEWMANN demonstrated[3] that the parameter

$$Y_x = \frac{t-t_0}{t'-t_0}$$

for the flow in the x direction for the case where there is no flow in the Y and Z directions
and

$$Y_y = \frac{t-t_0}{t'-t_0}$$

for flow in the y direction if there were no flow in the x and z direction, and if Y_z is similarly defined, then:

$$Y = \frac{t-t_0}{t_1-t_0} = Y_x\ Y_y\ Y_z$$

In this manner it is possible to solve a problem by constructing only a one-dimensional model, and by combining the result, to obtain the information for a three-dimensional body.

Many other problems, including heat storage problems, can be solved. In each case the problem has to be studied and the analogue technique evolved, and the conditions in which the body will work are very important.

The use of the model is not limited to heat-transfer problems. Any other phenomenon that can be represented by an equation similar to Equation (1) can be solved by this computer; this includes diffusional problems.

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66-492:621.86

BULK HANDLING OF POWDERS IN THE CHEMICAL INDUSTRY

Methods of handling solids are reviewed, including conventional pneumatic conveying and fluidized feed pressure conveying. The various techniques are considered in relation to particles of 10-1000 microns having bulk densities of 30-80 lb/cu. ft. Methods of feeding are discussed along with a number of problems such as solid:air ratio and energy losses in the various systems. Among the advantages of the technique by which the solids are fluidized initially before introduction into the conveying line is a far greater solid:air ratio. Applications of this method are described

by F. E. D'ARCY-SMITH

IT is almost impossible to list the numerous types of powder which are found in the chemical industry. It is also difficult to classify them according to weight, grain size and shape, bulk density, moisture content, moisture absorption and cost. However, the problem of handling these powders is with industry all the time.

The use of sacks and drums was once considered unavoidable, and has been accepted in some cases because they facilitate measuring and batching by weight or volume. Much thought has been given to the development of efficient handling methods for such containers, and ingenious handling equipment is often seen in use. Nevertheless, the cost of the containers, problems arising in filling, emptying and storing, disposing and reconditioning them has led to bulk handling wherever possible.

Mechanical handling equipment, such as belt or screw conveyors, grab cranes, bucket elevators, etc., are satisfactorily used, but the dust problem is often serious in such cases. Pneumatic handling through pipelines has provided possibilities for clean and dust-free operation even with very fine powders.

It is proposed here to discuss the pneumatic handling of powders with special reference to a method which achieves high conveying rates over long distances with low air volumes.

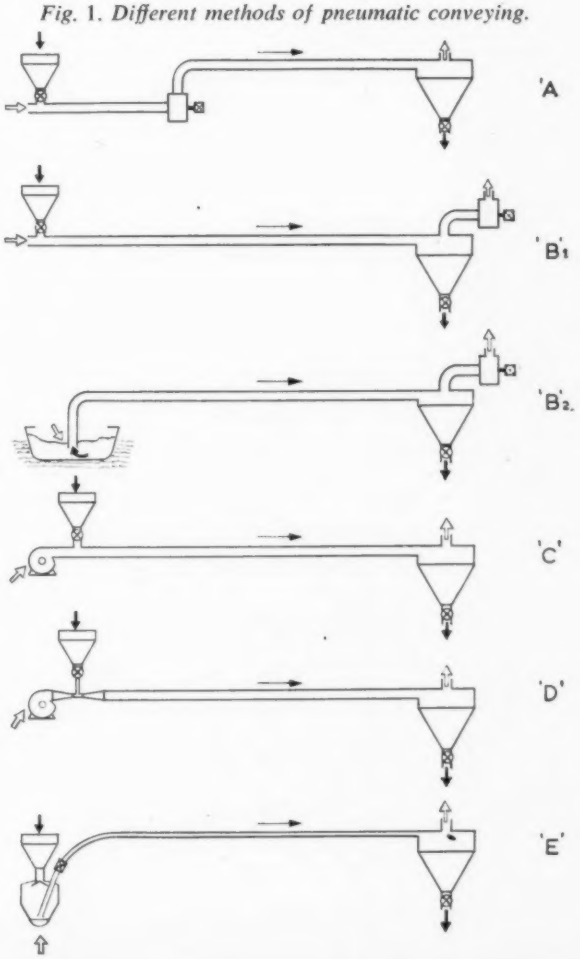
While pneumatic conveying is practicable for a wide variety of powders, granular materials and even for fairly large sized and heavy materials, it is proposed to consider here powders having a particle size range of 10 to 1000 micron, and a bulk density between 30 and 80 lb/cu ft.

Pneumatic Conveying Methods

Briefly, pneumatic conveying is the carrying of powder particles in an air stream which travels through a pipeline. Fig. 1 shows the main principles of the process, and illustrates different methods which are being applied. The various diagrams also illustrate the major difference between the more conventional types of pneumatic conveying and Fluidized Feed Pressure Conveying.

A. This method, which is similar to simple venting installations designed to suppress dust at grinding wheels and other dust-creating tools, consists of a suction intake, fan, conveying line and a cyclone. Only small quantities of powder can be carried because all the particles pass through the fan.

Fig. 1. Different methods of pneumatic conveying.



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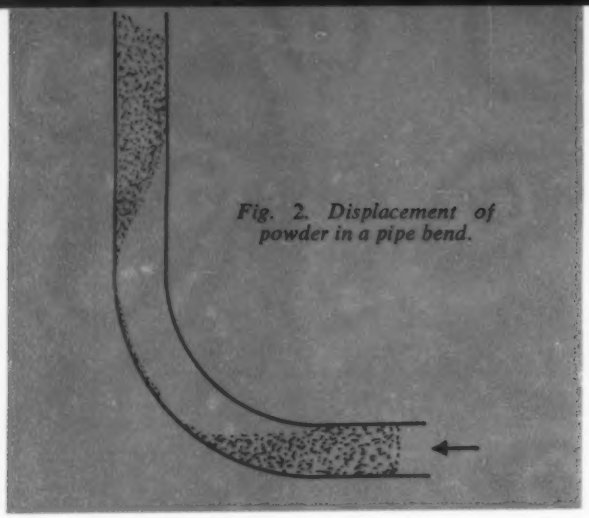


Fig. 2. Displacement of powder in a pipe bend.

B.1. The fan in this case is arranged behind the cyclone and handles clean air only. The pipeline and cyclone are under suction, and a feeder—for instance a rotary valve—regulates the flow of the powder entering the air stream. This principle may be applied to closed-circuit and air-swept grinding systems.

B.2. Here the material is not fed into the air stream but is entrained into the pipeline by the air required for conveying. This method is widely used for unloading large quantities of grain from ships.

C. Here the material is again fed into a pressurized air stream by a rotary valve which acts as a seal, or by a worm which provides a mechanical movement and creates a seal as long as the feed remains continuous. This method is used in many designs and is suitable for efficiently conveying large quantities. The valve or worm will concern both the engineer and the operator; first, because excessive wear of these moving parts leads to leakage and loss of efficiency, and, secondly, in the case of worm feeders, because the power consumption may become prohibitively high.

D. The powder is here fed into a pressurized system by the application of venturi principles. Difficulties arise with large quantities of material because the necessarily large cross-section of the feed chute destroys the shape and the efficiency of the most carefully designed venturi.

E. This method is different from all the above because the powder to be conveyed is first fluidized by the air stream in a closed feed vessel, and the fluidized mass then enters the conveying line under pressure, gradually changing from dense fluidization to dispersal as it travels along the pipeline. The illustration shows an arrangement which works intermittently in batches, but twin pressure vessels are often provided to give almost continuous conveying, while special automated designs are available for uninterrupted flow of powder. This conveying method works with very low quantities of air, but at high pressures, dependent on output and conveying distance. It is later described in greater detail and a number of actual installations will be discussed.

Principles of Pneumatic Conveying

It is interesting to examine some of the basic principles and problems of pneumatic conveying before the features of the Fluidized Feed Pressure Conveying method are considered, because they classify the reasons for the higher efficiency of this latter method.

When a particle of powder is introduced into the centre of a vertically rising air stream, it will either drop, float or travel upwards. The air velocity at which a given particle floats is the floating velocity, and for the particle to travel the air velocity must be higher than the floating velocity.

Conditions in a horizontal air stream are somewhat different, in so far as the weight of the particle must be balanced by other forces which counteract gravity. It is mainly turbulence which provides these forces, and turbulence may be created or accentuated by particles settling out to form an obstruction similar to an irregular pipe surface.

It will be readily apparent that the air velocity must be higher than the conveying velocity for both vertical or horizontal transport. With many particles conditions remain largely the same, although individual particles may change their theoretical velocity due to the friction created by collision with other particles or the walls of the conveying pipe.

The movement of a stream of particles in a pipe bend is shown in Fig. 2. Momentum and centrifugal force displace the particles towards the outer wall, and friction increases between particles and between particles and wall. This leads to a further reduction of the mean conveying velocity, and the re-dispersal as well as the reacceleration of the particles will consume energy greater than that required for conveying in the same length of straight pipe.

The changes in conveying velocities in a pipeline system consisting of straight vertical, inclined and horizontal lengths with connecting bends are illustrated in Fig. 3. The air velocity is here shown constant, although this is not absolutely correct. It can be seen that the conveying velocity never reaches the air velocity, and the mean conveying velocity is much lower. The repeated re-acceleration of the particles consumes considerable energy.

One of the main problems of pneumatic conveying arises in connection with the "loading" of the air stream. Apart from the question of how to introduce the powder into the air stream, there is the matter of deciding how much powder can be carried. The aim is to introduce as much powder as possible into the smallest possible volume of air. In practice there are very strict limitations in this respect, because energy is consumed for the acceleration to a velocity considerably higher than the floating velocity of every

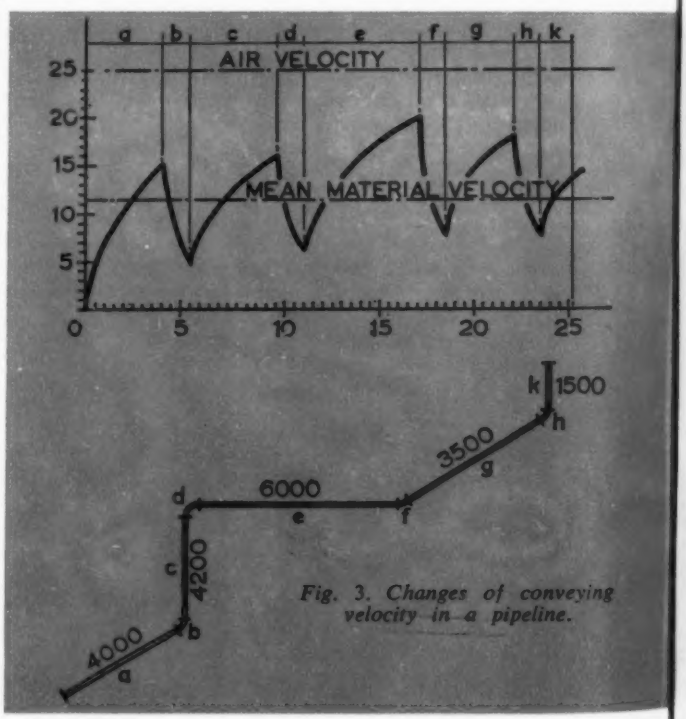


Fig. 3. Changes of conveying velocity in a pipeline.

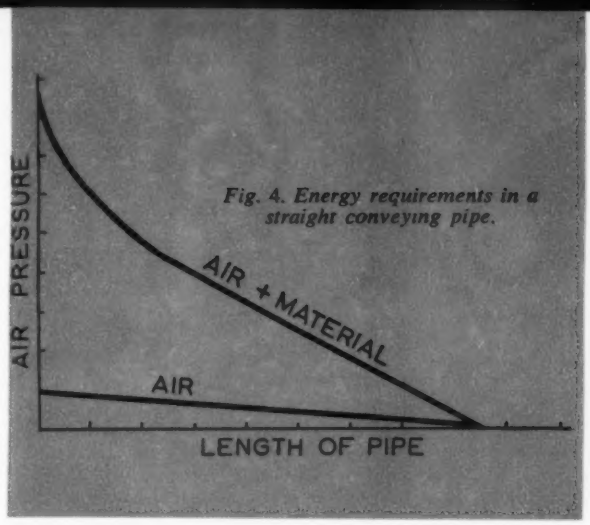


Fig. 4. Energy requirements in a straight conveying pipe.

particle of material which enters the air stream. If the energy required to do this exceeds the energy contained in the air stream, the particles will not be accelerated, but will settle out, causing a reduction of the cross-sectional area of the air stream. The higher air velocity at this point will cause some re-entrainment and conveying, provided that the extra power or air pressure is available. If this power is not available further settling will take place, the pipeline will become blocked and conveying will eventually cease altogether. The same conditions will arise if, with an otherwise satisfactory loading of the air stream, the air velocity is reduced.

From this it may be concluded that the risk of "overloading" or blockage is a minimum when the particles are fairly uniformly distributed over the cross-section and length of the pipe. Once the satisfactory degree of loading for a specific air velocity has been established, a controlled. regulated feed of powder to the air stream will provide a relatively simple means of ensuring continuous conveying, and prevent blockages so long as the air velocity is maintained. While economic air velocities providing efficient conveying can vary within wide limits, powders will probably be conveyed by air moving at hardly less than 3000 fpm and possibly as high as 10,000 fpm.

Practical applications at these velocities are reported to operate at a loading of as little as $\frac{1}{2}$ lb/lb of air or as much as 10 lb/lb; a reasonable average figure of 5 lb/lb being quoted in the literature. If these 5 lb apply to a powder of bulk density 50 lb/cu ft, they represent less than 14.4 cu in carried in about 13 cu ft of air. The reason for this very dilute solids-air mixture becomes evident when the energy required for conveying is examined in terms of pressure drop along the conveying pipeline. The energy—as applied to a length of straight pipeline delivering to atmospheric pressure—consists of two main components:

(a) that pressure loss normally occurring when moving clean air through the pipeline at the particular velocity; and
(b) that additional pressure loss resulting from the acceleration of the particles and from friction between the particles and between particles and wall.

The theoretical relationship between these two components in the case of straight pipe is shown in Fig. 4, where the straight line represents pressure drop over length of the conveying pipe in the case of clean air. The upper curve shows the overall pressure drop for the solids-gas mixture. The initial pressure drop, as represented by the curved part of the upper line, occurs in that part of the conveying pipe which is traversed at velocities lower than the ultimate conveying velocity, which might be described as the acceleration section. The pressure drop then continues in inverse proportion, mainly representing friction energy.

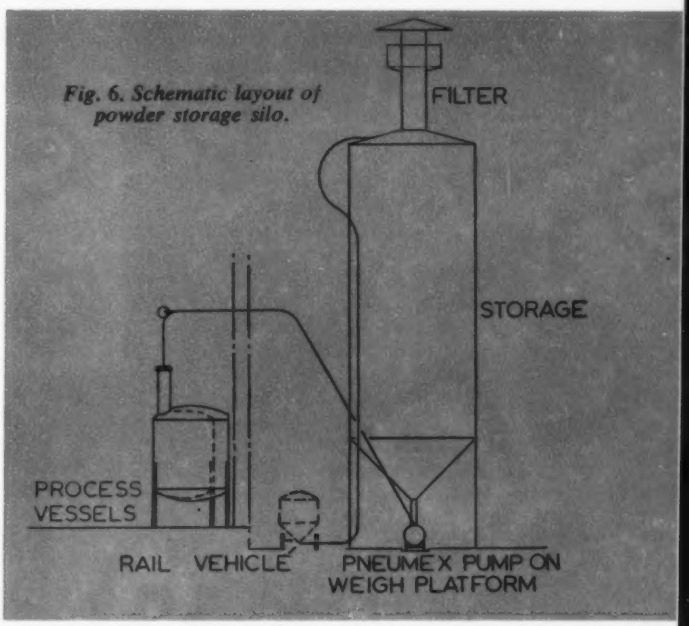


Fig. 6. Schematic layout of powder storage silo.

The conveying velocity would be largely as shown for any of the straight pipe sections in Fig. 3. It will be appreciated that higher loading will call for higher initial pressure, and that the initial pressure rises with increased air velocity and length of conveying line, but the initial acceleration in all cases absorbs a high percentage of the power.

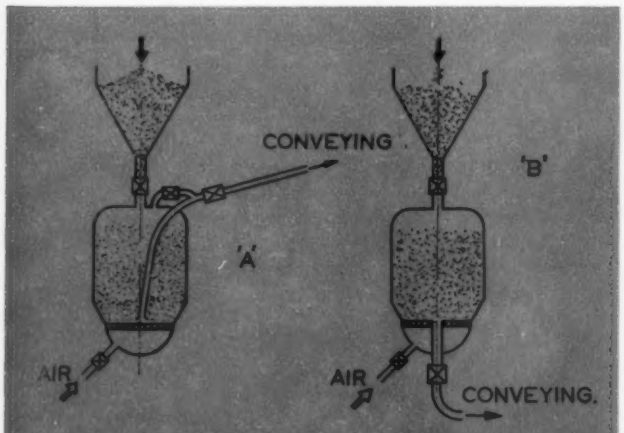


Fig. 5. Fluidized feed powder pump.

Fluidized Feed Pressure Conveying

The position becomes materially different when the particles are introduced into the pipeline in a state of dense fluidization created by high-pressure air. With this type of conveying the "loading" of the air is based on different principles, and the quantity of powder carried is unlikely to be less than 25 lb/lb of air, perhaps as high as 100 lb/lb, a reasonable average being about 50 lb/lb. Comparative volumes would be about 14.4 cu in of material carried in about 1.3 cu ft of free air. This is a much denser mixture than that encountered in conventional pneumatic conveying systems, and the diameter of the pipeline will be much smaller.

The reason for this can be seen by referring to Fig. 5 (a).

Fig. 7. Centralized storage and distribution of powders.

Once the pressure vessel, or blowing egg, contains its charge of powder, the feed valve is closed and the air valve opened. The valve in the conveying line is now closed. Air enters the material through a suitable porous medium until the necessary initial conveying pressure is reached in the vessel. The conveying valve is now opened and air continues to pass through the powder at what amounts to a fluidizing velocity. The bulk of the powder expands along the pipeline in accordance with the normal laws of fluidization. In addition to this expansion, which will continue from the dense phase of fluidization to the dispersed stage there is, simultaneously, the pushing effect of the high pressure in the vessel acting on the fluidized mass largely as if it were a liquid.

Fig. 5 (b) represents the operating principle of most road and rail powder tankers now in use for cement and many other materials. In spite of the small difference in design, the powder:air ratio is not as good as with the method shown in Fig. 5 (a). The reason is that the air entering the vessel tends to pass to the conveying line without fluidizing the bulk of the vessel contents. While this has the advantage of requiring air at a lower pressure, it has the disadvantage of lower conveying rates, lower "loading", longer conveying time, and also the limitation of conveying distances. A most desirable characteristic of this conveying method is the absence of mechanical moving parts either in the pressure vessel or in the pipeline. Wear is limited to a few valves, and to that arising from abrasion in the pipeline. The general principles and features of pneumatic conveying—with certain modifications—apply here also, but the acceleration of the particles, the immediate uniform distribution, and the much lower initial velocities cause changes in emphasis, especially with short conveying distances and in the first sections of longer pipelines.

Applications

An installation where Fluidized Feed Pressure Conveying is applied is shown in Fig. 7. The powder arrives in B.R. air discharging vehicles which operate on a version of the method shown in Fig. 5 (b). This vehicle is supplied with air from a stationary compressor and delivers its contents into the silo. The powder pump is installed below the silo

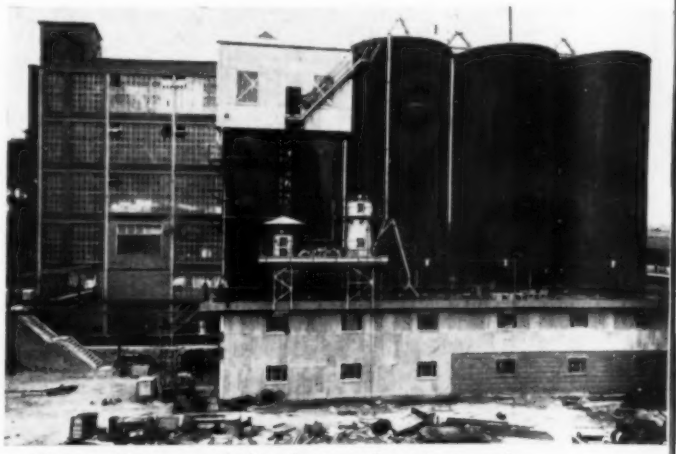


Fig. 9. Storage and distribution plant for powders.

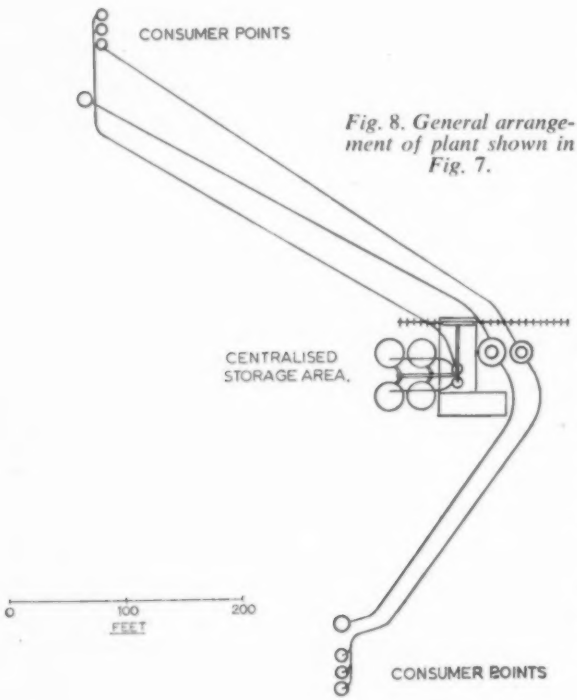


Fig. 8. General arrangement of plant shown in Fig. 7.

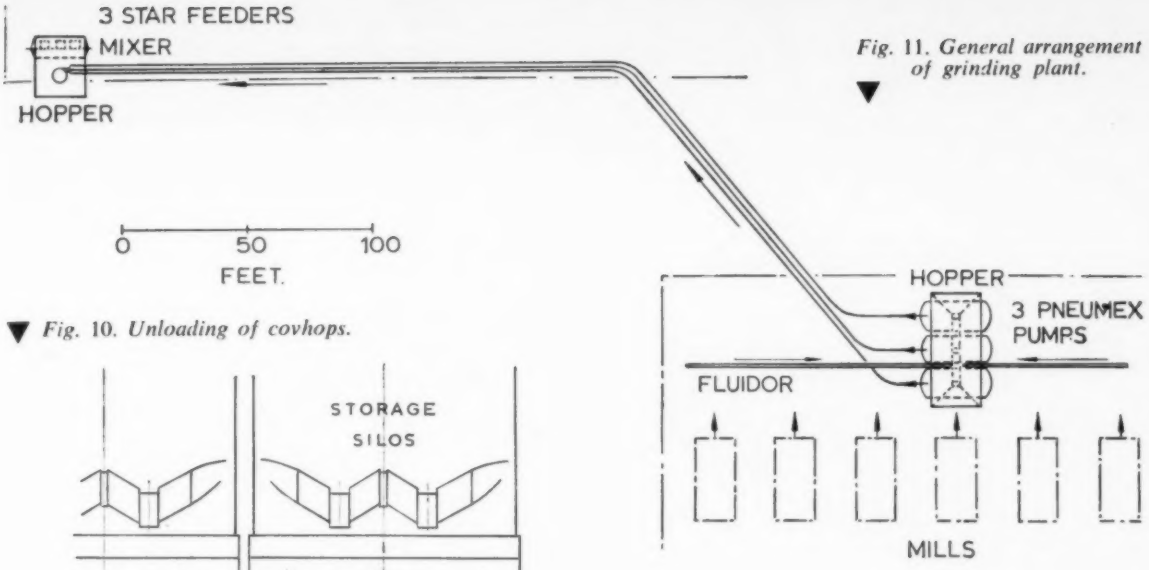
on a weigh scale for exact batching. The pump conveys its measured contents to a reactor vessel, the conveying line terminating in the vessel below liquid level.

Fig. 7 shows a number of storage silos for five or six different powders. The powders arrive either in B.R. covhops, in air-assisted gravity discharge road vehicles or in Fluidized Feed Pressure Conveying rail or road vehicles. The general arrangement plan is shown in Fig. 8. The various pipelines are shown leading from the various pumps to the different consumer points. The maximum conveying air pressure is 38 psi.

A similar storage and distribution installation is seen in Fig. 9. Here the storage silos are supported above a railway siding, the various materials arriving in covhops. Fig. 10 shows the relative location of covhops, pump and silos.

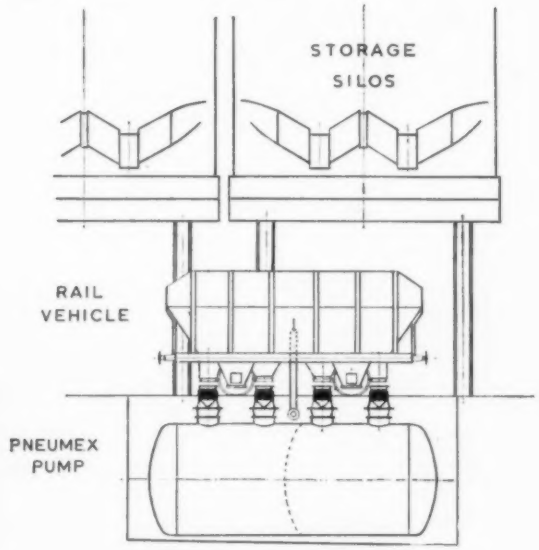
Special problems associated with unloading covhops in the shortest time led to the provision of a pump vessel large enough to accept the whole contents of a covhop. The material in this case has a bulk density of 30-34 lb/cu ft, the conveying pipeline has a diameter of 6 in., and the power consumption of the compressor is about 0.88 kWh/ton conveyed.

An application concerned with the production of a powder, rather than its storage and distribution, is illustrated in Fig. 11. Here the product of a number of grinding mills is collected in a fluidized conveyor and delivered, in rotation, to one of three pumps which work to a pre-



▼ *Fig. 10. Unloading of covhops.*

Fig. 11. General arrangement of grinding plant. ▼



determined time schedule. There are three separate conveying lines each 5 in. in diameter and about 350 ft long. The installation handles about 100 tons/hr of powder with a bulk density of about 45 lb/cu ft.

In a Canadian plant designed and supplied from this country the silos are 65 ft in diameter, 100 ft high and fully fluidized. Two 4-in. parallel pipelines carry the contents of five of these large storage units to production.

All these installations, which have conveying potentials of from 29 to 100 tons/hr, rely on pipelines of from 3 in. to 6 in. diameter and the solids : air ratio varies from 62 : 1 to 42 : 1, corresponding to 1.6 per cent to 2.4 per cent of air by weight of material conveyed.

Fig. 12 shows an installation consisting of a conveying line of about 1800 ft overall length. The pump operates at a conveying pressure of about 75 psi, and 4.6 per cent weight of air is used. An interesting feature of this plant, which has a conveying capacity of about 22 tons/hr for a powder with a bulk density of about 55 lb/cu ft, is the variation in the diameter of the pipeline. The beginning of the pipeline has 3 in. bore increasing to 3½ in., and for the terminal section to 4 in. This was done in order to reduce conveying velocities, thereby to lower the initial air pressure required and to reduce abrasion in the pipeline. The theoretical air velocity in this case is as low as 1670 fpm at the beginning, rising to about 5700 fpm at the delivery end of the line.

For dust collecting an air filter is frequently installed on the top of a silo. This type of suction filter is often used with very dusty materials to clean the air after conveying, and it discharges any powder recovered into the storage silo. Such filters may be necessary to supplement or replace the cyclones shown in Fig. 1.

Many factors contribute to the overall efficiency of Fluidized Feed Pressure Conveying systems—namely the lower cost of supplying the air required for conveying, the much lower capital cost of small-diameter pipelines, and the smaller size and lower cost of the necessary cyclone and filter equipment.

The lack of complete knowledge of all the problems inherent in this system forces the designer to apply safety margins which it may be possible to reduce in the future. This is certainly a field in which the scope for scientific progress is great.

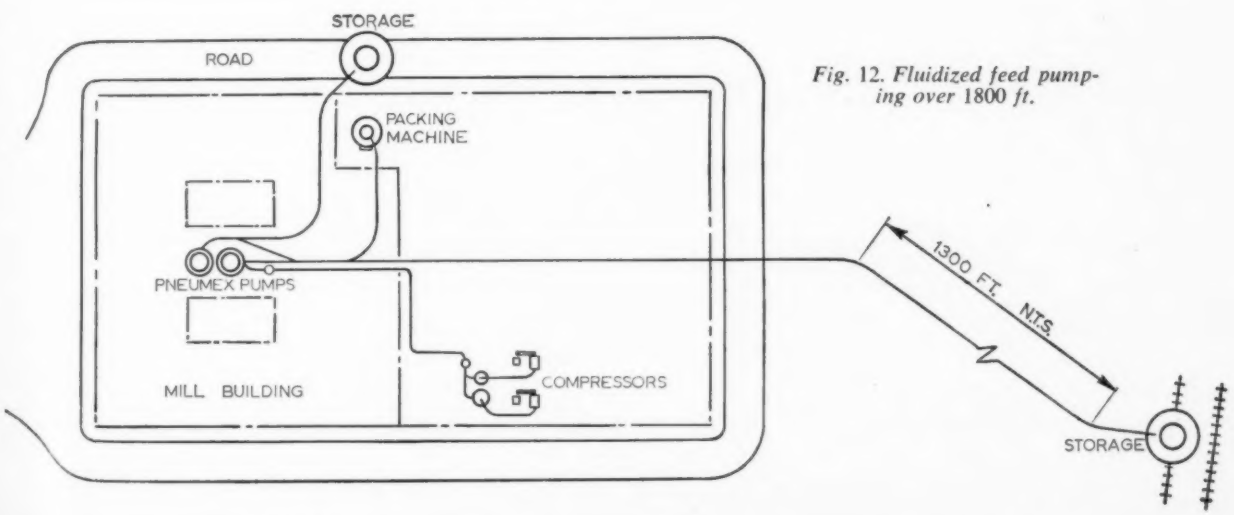


Fig. 12. Fluidized feed pumping over 1800 ft.

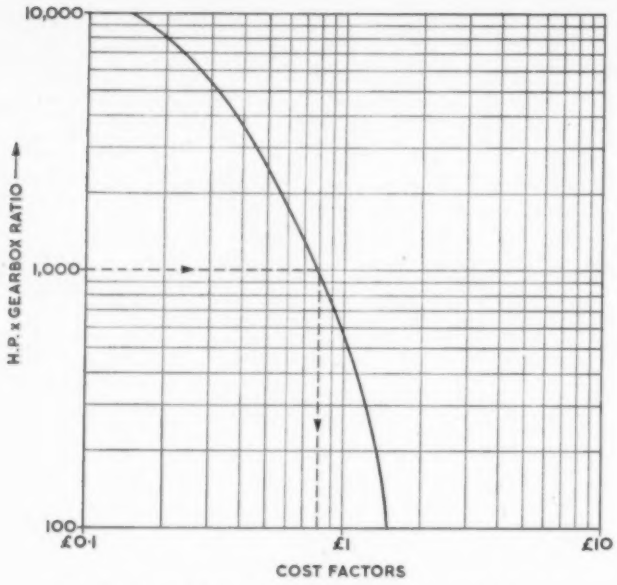


Fig. 1. Costs of gearboxes. The cost of gearboxes is estimated by multiplying the values of the x- and y-axes. For example a gearbox of 100 hp and ratio 1 : 10 will cost 100 × 10 × £0.8 = £800. For conical gearboxes add 15 per cent.

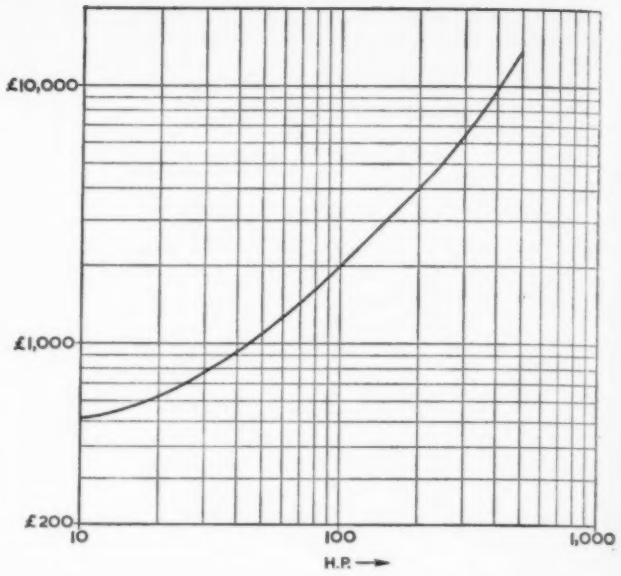


Fig. 2. Costs of diesel engines, 1000 rpm.

COSTS OF PROCESS EQUIPMENT

by M. STOGENS

THROUGHOUT the chemical industry there is nowadays an ever-increasing consciousness of the importance and the value of "costs". Although we are all cost-minded, we often fail to accurately estimate the costs of process plants and equipment due to the lack of data. Up-to-date information is essential for accurate estimating these days, otherwise the resultant "guesstimate" may turn out to be a costly error.

In this connection, it must be admitted that contractors have greater experience and better intuition than the chemical concerns. Further, contractors attach great importance to their bids and to costs on account of the competition which exists in their business.

The charts presented here will be found useful by those who need to determine the costs of auxiliary equipment which is widely used in the chemical industry.

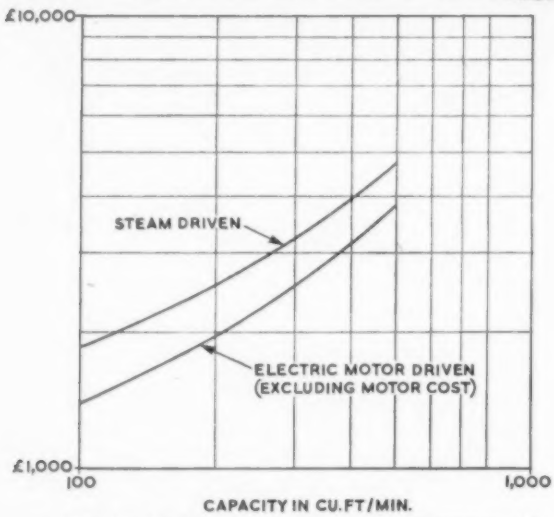


Fig. 3. Costs of two-stage air compressors; discharge pressure 250 psig.

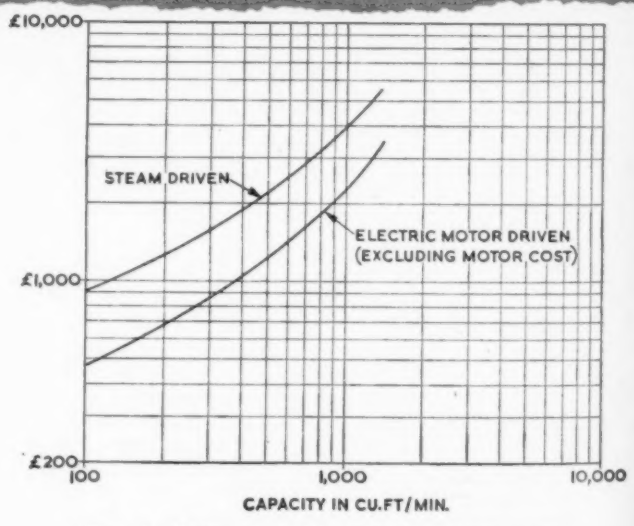
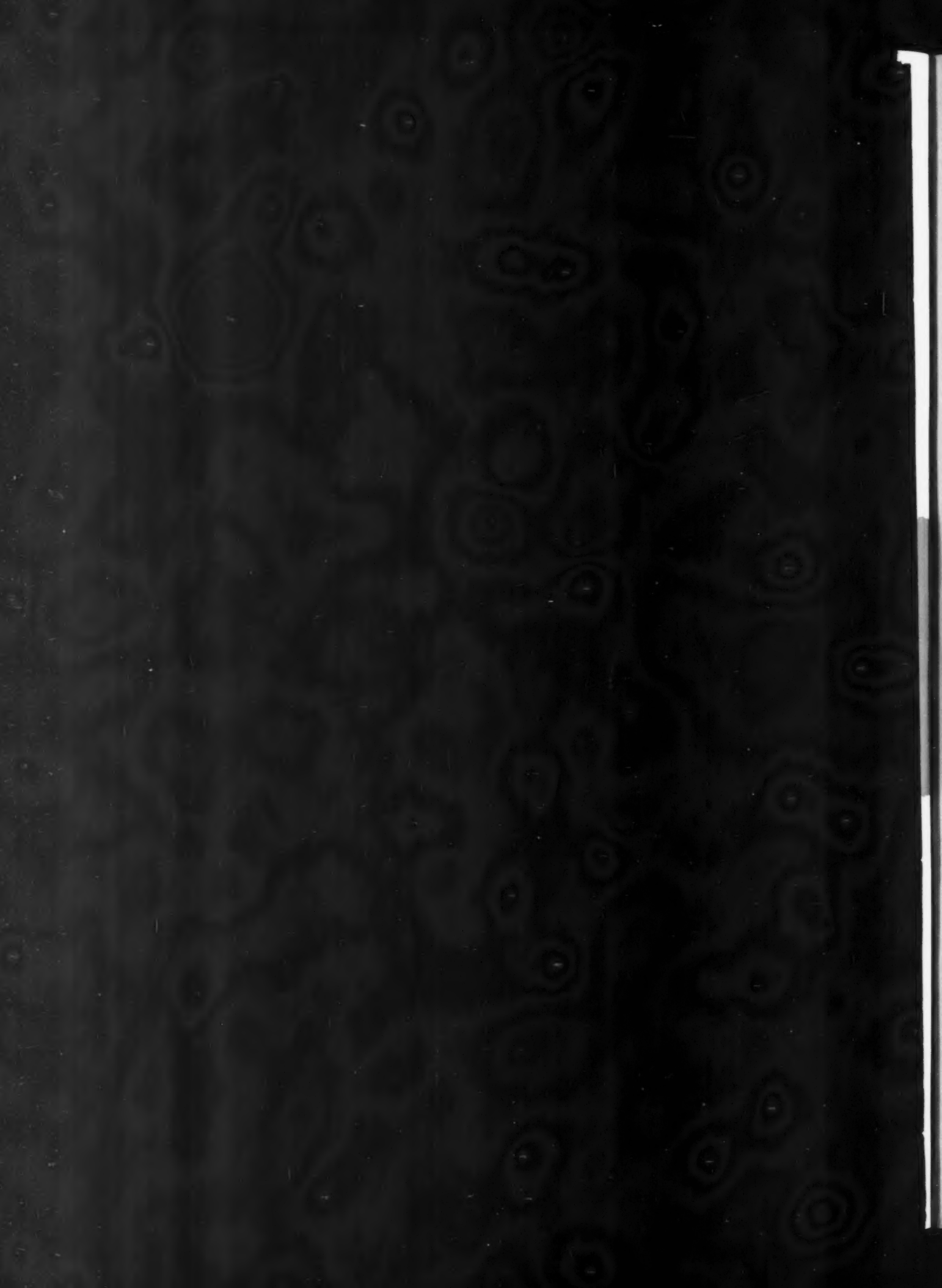


Fig. 4. Costs of single-stage air compressors; discharge pressure 25 psig.



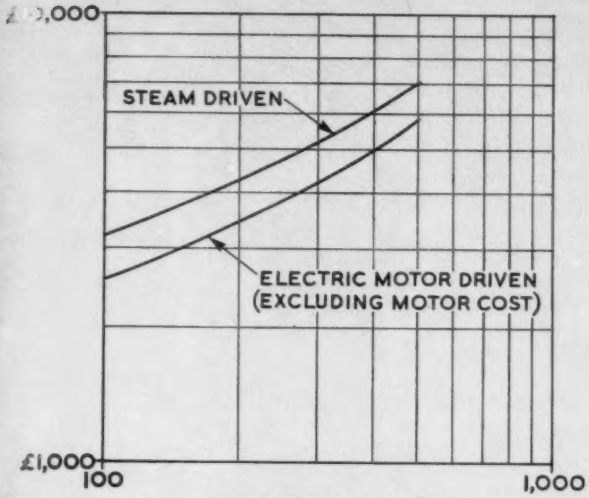


Fig. 5. Costs of three-stage air compressors; discharge pressure 1200 psig.

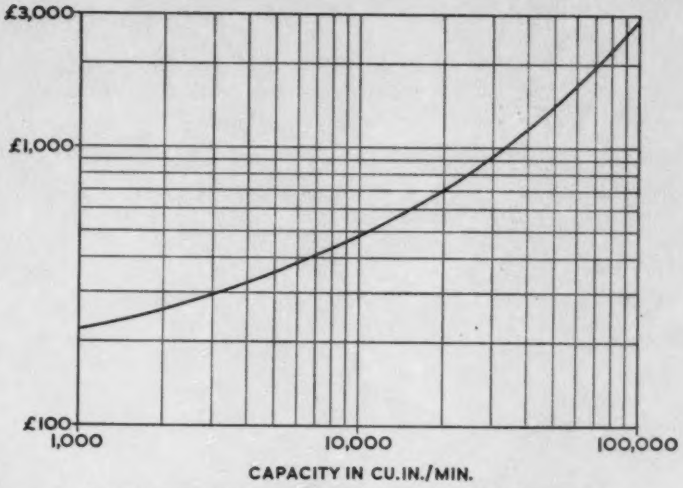


Fig. 6. Costs of steam-jacketed positive-displacement pumps, including electric motors; discharge pressure 100 psig.

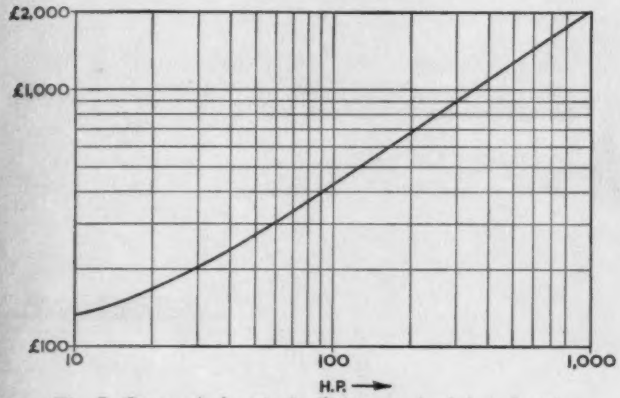


Fig. 7. Costs of electric facilities required for electric motors—includes starters, all electric connections and 150 ft of wire.

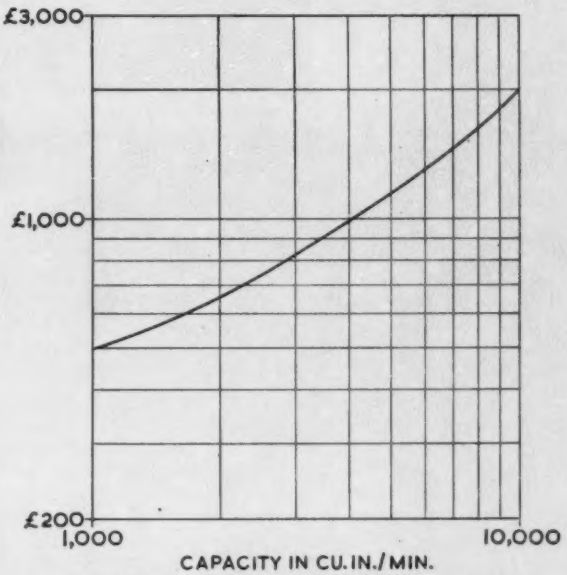


Fig. 9. Costs of steam-driven reciprocating pumps; average discharge pressure 150 psig.

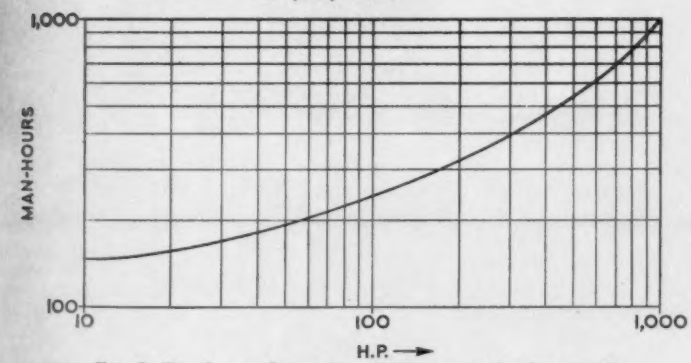


Fig. 8. Total man-hours required to completely install centrifugal pumps with electric motors.

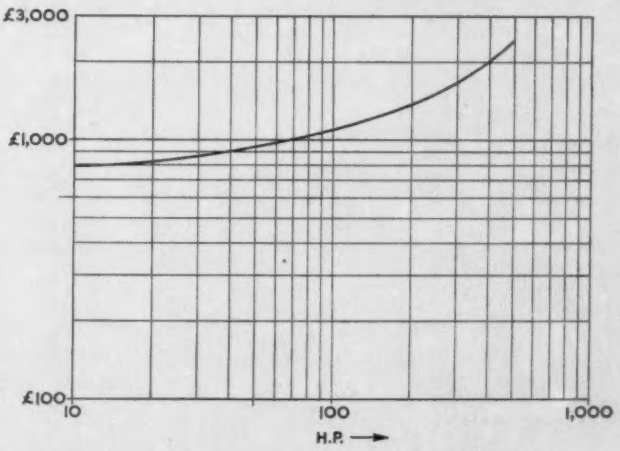


Fig. 11. Costs of back pressure turbines, 3000 rpm.

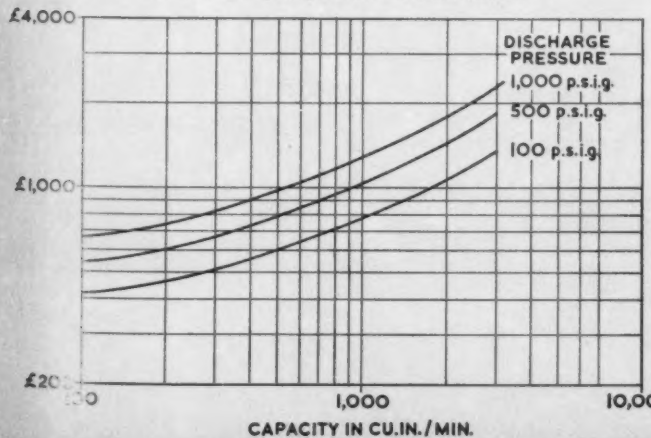


Fig. 10. Costs of variable stroke proportioning pumps, including electric motors.

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MASS TRANSFER APPLICATIONS

In many of the mass transfer operations such as liquid-liquid extraction, a considerable portion of this transfer is by eddy diffusion rather than by skin friction or molecular diffusion. If, however, the "skin friction" mass transfer for such a system is isolated by performing the operation in a wetted wall tower, it should then be possible to relate this to the total mass transfer (skin + eddy) by means of industrially determined "enhancement factors", and if, in addition, a correlation can be obtained from such wetted wall experiments relating the variables, then these enhancement factors can be used for the prediction of mass transfer coefficients for industrial plant and systems from the physical properties of the system components. In packed towers, as used for industrial extraction, the packing is a dispersing medium rather than a contacting surface, but the effective area of the dispersed fluid through which the mass transfer takes place can be related to the effective area of the packing by means of the sphericity of the packing—and the respective surface tensions of the components of the system

by F. W. MOLYNEUX

ALTHOUGH a considerable amount of data has been accumulated over the past twenty or thirty years on the performance of packed towers in extraction, apart from TREYBAL[1] and PRATT[2, 3] and co-workers, few other workers have presented data for design purposes.

In extraction in packed towers, in addition to the variation in mass transfer rates from system to system, owing to different physical properties it has been found that the extraction rates can be influenced by:

(1) Choice of dispersed or continuous phase.
(2) Wetting or non-wetting of the packing by the dispersed phase.
(3) Size and type of packing.
(4) Height of towers and influence of end effects.
(5) Direction of extraction.
(6) Hold-up of dispersed phase.
(7) Velocity of liquid flow.

Liquid Film Equations in Extraction

The process considered is the transfer of a solute from a raffinate phase R to an extracting phase E, the same relationships being written for the transfer of solute in the opposite direction by assigning the opposite algebraic sign to the concentration differences.

The following equations are adopted for extraction from the corresponding equations for absorption by considering the gas phase and gas film to have been replaced by a liquid phase and its corresponding liquid film.

For solute transfer across a liquid film in extraction under steady-state conditions at any point in a continuously functioning apparatus:

$$N = K \,.\, A\,(C_L - C_i) = K \,.\, A\, C_{av}\,(x_L - x_i)$$

By analogy the film extract coefficient given by $K = \dfrac{D_L}{\delta x_m}$; δ = effective film thickness; $x_m = \dfrac{x_L + x_i}{2}$.

All extraction processes are carried out according to the two-film theory across two liquid films in series.

Relationships between overall and individual film mass transfer coefficients can be derived on the basis of the two-film theory to give:

$$\frac{1}{K_{OE}} = \frac{1}{k_E} + \frac{M}{k_R}$$

$$\frac{1}{K_{OR}} = \frac{1}{k_R} + \frac{1}{Mk_E}$$

where M is the slope of the equilibrium curve.

SHERWOOD and GORDON have shown that these relationships between overall and individual film coefficients hold experimentally for some systems and are independent of the actual mechanism of mass transfer.

The determination of the height of a liquid extraction column involves finding first the number of theoretical stages or transfer units, and, second, the height of a column equivalent to a theoretical stage or transfer unit.

It has been found generally for tall columns that although the operation is continuous and not intermittent, as in stagewise extraction, the two concepts of equilibrium stages or differential transfer units give results that are numerically almost identical.

Since most of the liquid-liquid equilibrium data is presented in the form of a plot on triangular co-ordinates, it is generally preferable to commence the design of a column using this data and obtaining the number of equilibrium stages by means of any of the several graphical methods available.

In order to convert this to determine the height of an operating column, it is then necessary to determine by some method the height of the equivalent theoretical stage (H.E.T.S.). This must normally be obtained from previous experimental work with the system, but if the H.E.T.S. could be related in some way with the H.T.U., and from this with the mass transfer coefficients, it has been suggested that the H.E.T.S. itself might be computed from easily

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available physical data for the components of the extraction system.

The Height of a Transfer Unit (H.T.U.) is given for dilute solutions by:

$$\text{H.T.U.}_{OR} = \frac{R}{K_{OR}\, a_v \,.\, C_{Rav}\, A.}$$

where $$C_{Rav} = \frac{C_R + C_R^*}{2};$$

a_v = interfacial area/unit volume; and

$$\text{H.T.U.}_{OE} = \frac{E}{K_{OE}\, a_v\, C_{Eav}\, A}$$

The overall coefficients K_{OE} and K_{OR} are related to the film coefficients as already stated, and these should be estimated in the manner of other mass transfer operations from the physical properties of the system. GAYLER and PRATT[3] proposed the following correlation for the respective film coefficients of mass transfer:

$$\frac{k_d\, F\, h_d^{1+m}}{V_d} = 6.4 \times 10^{-5}\, \text{Re}_d^{0.5} \left[1 + \frac{V_c\, h_d}{V_d\,(1 - h_d)}\right]^{1.5} \quad \ldots . (1)$$

$$\frac{k_c\, F\, h_d^{1+m}}{V_d} = 5.3 \times 10^{-5}\, \text{Re}_d^{0.5} \left[1 + \frac{V_c\, h_d}{V_d\,(1 - h_d)}\right]^{1.5} \quad \ldots . (2)$$

m = (0.45 − 0.20) × droplet diameter (d_p), in;
F = fractional voidage of packing;
h_d = fractional hold-up of the dispersed phase in the packing voids;
V_c, V_d = superficial velocities of the continuous and dispersed phases respectively ft/hr based on the empty column.

In both gas absorption and distillation mass transfer progress has been reported on the determination of film mass transfer coefficients by assuming that the mechanism of mass transfer in a packing is analogous to that in a simple wetted wall column, but that the extra turbulence induced by the packing increases the mass transfer coefficient by a factor denoted by R_a which is characteristic of the packing.

BRINSMADE and BLISS[4] have reported correlations for extraction in a wetted wall tower as follows:

For the core fluid $$\frac{k_c\, d}{D_L} = 1.07\, (\text{Re})^{0.67} \left(\frac{\mu}{D_L \rho}\right)^{0.62}$$

For wall fluid

$$\left(\frac{\mu^2}{\rho^2 g}\right)^{1/3} \frac{k}{D_L} = 0.00135\, (\text{Re}) \left(\frac{\mu}{D_L \rho}\right)^{0.62}$$

The first expression is similar to that obtained for gas film coefficients in a standard 1-in. wetted wall column and the second is very similar to the corresponding expression for liquid film coefficients obtained in a standard disc tower.

Both these coefficients have been related by MORRIS and JACKSON[5] to those in a packed tower by use of the enhancement factor R. In the above equations, d is the diameter of the wetted wall column, and the velocity used in the Reynolds number (Re) is the relative velocity of one fluid to the other and is effectively the continuous phase velocity in the empty tower V_c divided by the fractional voidage of the packing ϵ.

Liquid Film Coefficients and the H.T.U.

The mass velocity of the continuous phase V_c is obtained from the flooding correlations for packed extraction columns obtained by DELL and PRATT[2] and an operating velocity of 50 per cent of the flooding velocity is chosen. The empty tower velocity of the dispersed phase V_D is calculated on the tower diameter corresponding to this value of V_c.

The film coefficients k_c and k_d are then estimated from formulæ of BRINSMADE and BLISS[4] calculated as follows:

(1) Calculate the continuous phase velocity v_c in the packing from $v_c = \frac{V_c}{\varepsilon}$, where ϵ = fractional voidage.

(2) Calculate the irrigation rate for the dispersed phase
$$= \frac{\text{Liquid rate of dispersed phase ft}^3/\text{hr}}{\text{Total periphery of packing ft}}$$

Total periphery of packing = 4 × surface area of packing per unit volume a_v

$$v_d = \frac{V_d}{4 \times a_v}$$

Symbols Used

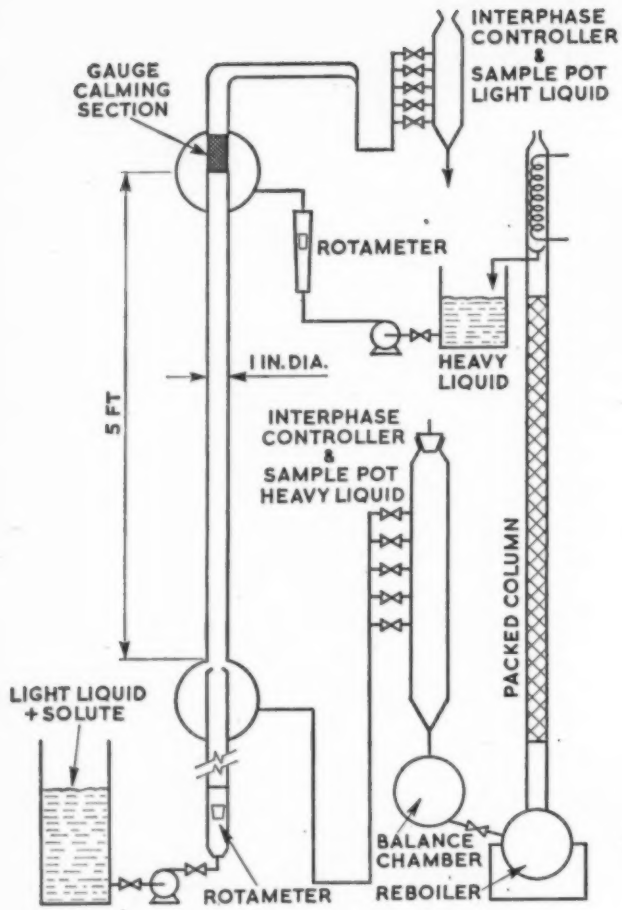
S = cross-sectional area of tower, ft²;
A = total interfacial surface between phases, ft²;
a = interfacial surface area per unit volume of tower, ft²/ft³;
c = concentration of solute in phases, lb mol/ft³;
k = individual film mass transfer coefficient, lb mol/hr ft²;
K = overall mass transfer coefficient, lb mol/hr ft²;
H.E.T.S. = height equivalent to a theoretical stage, ft;
H.T.U. = height of a transfer unit, ft;
m = distribution coefficient y/x at equilibrium;
R = raffinate solution solute included, basis lb mol/hr;
Re = Reynolds number;
Sc = Schmidt number;
V = superficial velocity, ft³/hr ft²;
v = velocity raffinate or extract phase, ft³/hr ft²;
x = mol fraction solute in raffinate solution, lb mol solute/lb mol raffinate;
y = mol fraction solute in extract solution, lb mol solute/lb mol extract;
E = extract solution solute included, basis lb mol/hr;
d = column diameter, ft;
D = diffusion coefficient, ft²/hr;
h = fractional hold-up in packing voids;
M = molecular weight of solute;
T = absolute temperature; Tc = critical temperature; *Tr = reduced temperature;* Tb = boiling point temperature;
N = mass transfer, lb mol solute.

Subscripts

t = total area;
c = continuous phase;
d = dispersed phase;
E = extract phase;
R = raffinate phase;
i = interface;
O = overall;
av = average;
v = unit volume of tower;
$*$ = equilibrium value;
L = liquid;
m = mean.

Greek Symbols

μ = viscosity consistent units, fph;
ρ = density, lb/ft³;
$\epsilon = F$ = fractional voidage;
δ = effective film thickness;
θ = sphericity of packing = surface area of sphere of equivalent volume / surface area of packing
γ = surface tension, dynes/cm.



Schematic arrangement of standard one-inch wetted wall column in solvent extraction.

(3) Then relative phase velocity for use in Re number $V = v_c + v_d$.

(4) Determine the value of k_c = film coefficient continuous phase for a standard 1-in column ($d = 1/12$ ft) from

$$k_c = 12.7\ D_{Lc} \left(\frac{V\rho_c\, d}{\mu_c}\right)^{0.67} \left(\frac{\mu_c}{D_{Lc}\rho_c}\right)^{0.62}$$

(5) Determine the value of k_d = film coefficient dispersed phase for standard 1-in. column ($d = 1/12$ ft) $k_d = 0.00135\ D_{Ld}$

$$\left(\frac{\rho_d{}^2\, g}{\mu_d}\right)^{1/3} \left(\frac{V\rho_d\, d}{\mu_d}\right) \left(\frac{\mu_d}{D_{Ld}\rho_d}\right)^{0.62}$$

(6) Multiply the above values for coefficients in 1-in. standard tower for the respective enhancement factors for the packing obtained from the tables in MORRIS and JACKSON.[5]

(7) Determine the overall mass transfer coefficient either on the base of the continuous or dispersed phase from:

$$\frac{1}{K_{Oc}} = \frac{1}{k_c} + \frac{M}{k_d}$$

$$\frac{1}{K_{Od}} = \frac{1}{k_d} + \frac{1}{Mk_c}$$

(8) Calculate the Height of the corresponding Transfer Unit from:

$$\text{H.T.U.}_{Oc} = \frac{E}{K_{Oc}\, a_v\, A}$$

$$\text{H.T.U.}_{Od} = \frac{R}{K_{Od}\, a_v\, A}$$

Correlation of H.T.U. and H.E.T.S.

The relationship between H.T.U. and H.E.T.S. may be obtained by comparing the driving forces acting in a transfer unit and over a theoretical stage. In the latter case, the driving force may be calculated in distribution co-ordinates as the log mean between $(y^* - y)$ and $\frac{mE}{R}(y^* - y)$.

The rate equation for the theoretical stage is then:

$$E(y^* - y) = K_{Oc}\, a_v \frac{\left(\frac{mE}{R} - 1\right)(y^* - y)}{ln\left(\frac{mE}{R}\right)} \times \text{H.E.T.S.}$$

which simplifies to:

$$\text{H.T.U.}_{Oc} = \frac{\left(\frac{mE}{R} - 1\right)}{ln\left(\frac{mE}{R}\right)} \times \text{H.E.T.S.}$$

$$\frac{R}{m.E} = \frac{\text{Slope of operation line}}{\text{Slope of equilibrium line}} = \frac{1}{r}$$

Since both of these slopes vary from top to bottom of the enriching and stripping section of the extraction column, a mean value for the ratio at the feed and either end of the column is taken as the value for that section.

The H.E.T.S. can then be determined from the following:

$$\text{H.E.T.S.} = \text{H.T.U.} \ln r/r - 1\ (r > 1)$$

$$\text{H.E.T.S.} = \text{H.T.U.} \ln \frac{1}{r}/1 - r (r < 1)$$

$$\text{H.E.T.S.} = \text{H.T.U. for } r = 1$$

The Effective Surface for Extraction Mass Transfer

In all expressions for the height of a transfer unit (H.T.U.), a factor a_v is contained in the divisor, representing the surface area over which the mass transfer takes place.

Experimental work by H. R. C. PRATT and others on the packed extraction column has demonstrated that the packing acts to provide additional surface for mass transfer by increasing the dispersion into droplets of the dispersed phase. This dispersion is found to be more dependent on the form of the packing, rather than its surface area, thus accounting for the success of packings such as the Schiebel, which consists of a mass of re-entrants and for the fact that the minimum size of Raschig ring in extraction was found to be ½ in. dia.

TABLE I.—Enhancement Factors for Tower Packings (R)

Type	Material	Size (in)	Voidage ε	Total Surface per unit Volume a_t (ft^2/ft^3)	Continuous Phase Enhancement Factor	Dispersed Phase Enhancement Factor
Random-packed Raschig Rings	Metal	2×2×⅛	0.92	30	0.67	3.3
		1×1×⅛	0.86	59.0	0.90	3.0
		½×½×⅛	0.87	115	0.88	3.1
	Stoneware	3×3×⅜	0.72	20.0	0.60	2.5
		2×2×⅜	0.74	28.0	0.65	2.7
		1½×1½×⅛	0.73	38.0	0.75	2.7
		1×1×⅛	0.80	56.0	0.88	2.7
		½×½×⅛	0.74	72.0	0.88	2.7
		½×½×⅛	0.73	115	0.88	2.7

Some success can be obtained in approximating to a value for this surface by the use of the following relationship:

$$\frac{a}{a_t} = \theta \left(1 - \exp - 0.4 \frac{V_d}{\rho_d}\right) \left(\frac{\gamma_c}{\gamma_d}\right)^{\frac{1}{2}}$$

a = effective surface for mass transfer/unit volume, ft^2/ft^3;
a_t = total surface area of packing/unit volume, ft^2/ft^3;
θ = sphericity = $\frac{\text{surface area of sphere of equivalent volume}}{\text{surface area of packing}}$;
V_d = velocity of dispersed phase/empty tower X section, $ft^3/ft^2\ hr$;
ρ_d = density of dispersed phase, lb/ft^3
γ_d, γ_c = surface tension of dispersed and continuous phase respectively, dynes/cm.

Conclusion

Values of D_L, the liquid diffusion coefficient for the solute in the appropriate solvent, were determined by the method recently proposed by IBRAHIM and KULOOR[7] and using the relationship derived:

$$\frac{\mu V_m}{4.5M} = D_L$$

D_L = diffusion coefficient, cm^2/sec;
M = molecular weight of solute;
V_m = molecular volume of solute;
μ = gaseous viscosity poise given by:

$$\mu = \frac{0.00270\ M^{\frac{1}{2}}\ T_c^{\frac{1}{2}}}{V_m^{2/3}} \cdot \frac{T_r^{3/2}}{T_r + 1.47\theta}$$

$\theta = T_b/T_c$;
T_c = critical temperature;
T_r = reduced temperature;
T_b = normal boiling point.

A comparison of some of the values for H.E.T.S. obtained by these methods against some of the experimental values given by MORELLO and POFFENBERGER[8] agree to within ±10 per cent, and suggest that the method might be worth further investigation, particularly in view of the results which MORRIS[6] has obtained with similar methods in distillation.

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Important Symposia for London, Athens and Paris

THE Third Congress of the **European Federation of Chemical Engineering** is to be held on the occasion of the Second Chemical and Petroleum Exhibition, which will take place at Olympia, London, from 20 to 30 June, 1962, inclusive. With the announcement by the Society of Chemical Industry that a symposium on "The Physics and Chemistry of High Pressures" is to be held at Olympia, the programme of the Congress is now complete. This is as follows:

20 June: Meeting on "Process Optimization".
21 to 23 June: Meeting on "Interaction Between Fluids and Particles".
25 June: Symposium on "Handling of Solids".
26 to 28 June: Symposium on "The Physics and Chemistry of High Pressures".

This last symposium will cover theoretical, experimental and applied work on high pressures (about 1000 atm upwards). The subjects to be discussed will include changes of phase, the study of optical, electrical and other physical properties, the equilibria and rates of chemical reactions, and work on new techniques, equipment and design. Work on transient properties, such as explosive and shock-waves, will not be discussed.

The organizers invite papers for inclusion in the programme. The title, or subject, and summary or other brief details of a proposed paper should be sent to: The General Secretary, Society of Chemical Industry, 14 Belgrave Square, London, S.W.1, England.

Another important event is the **First European Symposium on "Fresh Water from the Sea"** which will be held from 31 May to 3 June, 1962, in Athens, Greece. It is organized by the Union des Chimistes Hellènes and the Chambre Technique de Grèce, Section des Ingénieurs Chimistes, who invite all professional men engaged in this field to take part.

The following themes will be discussed: evaporation processes; electro-dialytic processes; desalting of brackish water.

The symposium will consist of four main lectures, for which invitations have been sent, and short papers. Papers may be presented in English, French or German.

The intention to read a paper, on new and unpublished work, accompanied by the proposed title and a short summary, should be communicated as soon as possible to the Secretariat, Union des Chimistes Hellènes, P.O.B. 1199, Omonia, Athens, Greece.

Upon acceptance of the paper by the Organizing Committee, authors will be asked to submit a final registration of their paper before 31 October, 1961. The manuscript, ready for printing, including all illustrations and a brief summary, must be sent to the Secretariat before 31 December, 1961.

The VIe Salon International de la Chimie will be held from 25 April to 4 May, 1962, at the Centre National des Industries et des Techniques (C.N.I.T.), Place de la Défence, Puteaux, Paris, France.

About 1400 firms from 25 countries are expected to exhibit a variety of products classified in the following groups: Group A: Chemical Products; Group B: Laboratory Equipment and Apparatus; Group C: Chemical Engineering Materials, Plants, Services and Industrial Process Control; Group D: Protection from Corrosion; Group E: Nuclear Techniques; Group F: Research and Documentation.

Firms wishing to exhibit at the Salon should apply for information regarding the renting of a stand to the Service des Exposants, 28 rue Saint-Dominique, Paris 7e. In conjunction with the VIe Salon will be held the Conférence Internationale des Arts Chimiques, at the Maison de la Chimie, 28 rue Saint-Dominique, Paris 7e. This Conférence will consist of a series of scientific and technical meetings on Chemical Engineering, Corrosion, Oils, Fats and Waxes, and the "Journées Techniques de Paris". Persons wishing to attend the Conférence can obtain full details and registration forms from the Conférence Internationale des Arts Chimiques.

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DIFFUSIVITIES OF ORGANIC ACIDS IN ETHANOL-WATER MIXTURES

Diffusivities of organic acids in ethanol-water mixtures were determined at 25°C using the Northrup and Anson diaphragm cell. An empirical equation for the calculation of these diffusivities has been proposed, and the observed results are found to agree satisfactorily with the proposed equation

by G. N. BHAT

DIFFUSION of solutes in liquids is the controlling factor in many operations involving mass transfer, and hence has received considerable attention. The earliest quantitative measurements in the field of diffusion in liquids were reported by GRAHAM[12] and by BEILSTEIN.[3] Since then various workers have investigated this problem with a view to studying one or more of the following: (a) determination of particle size; (b) estimation of ionization of colloidal particles; (c) determination of frictional coefficients; (d) evaluation of reaction rates. Reports on diffusion in liquids have been given by FÜRTH,[9] WILLIAMS and CADY,[22] DUCLAUX,[6] NEURATH,[18] COHN and EDSALL,[5] HARNED and OWEN,[14] HARNED,[13] BRIDGMAN and WILLIAMS,[4] GEDDES[10] and LONGSWORTH[15]; and a fairly complete list of apparatus developed from time to time is given by WEISSBERGER.[10] All these studies, however, have been mostly confined to measurement of diffusivities of solutes in single solvents, although SHEINKER[20] has confirmed the dimerization of palmitic acid in 10 g/l solution by diffusion measurements in ethanol-water mixtures. Detailed studies on the diffusion of solutes in solvent mixtures, in general, are lacking. As such, diffusivities of organic acids in ethanol-water mixtures were determined and attempts made to correlate the results obtained in such a way as to derive a general empirical equation by which the diffusivity of any solute in any solvent mixture could be calculated. Further experimentation seems necessary, however, to test the general applicability of the expression proposed.

The NORTHRUP and ANSON[19] diaphragm diffusion cell was used in these measurements. The mechanical stirring of the solutions on both sides of the diaphragm was achieved by a method similar to that used by MOUQUIN and CATHCART.[17] Enclosed in each compartment of the cell were two glass spheres, one slightly heavier and the other slightly lighter than the solution. The cell was mounted on an axle, inside a constant temperature oven adjusted to 25 ± 1°C, in the plane of the diaphragm, so that the cell could be rotated slowly end over end as the diffusion proceeded and the glass spheres in the compartments kept the solutions stirred as the cell rotated.

Properties of the diffusing acids used in these investigations are given in Table I.

Integrating the FICK equation[8] and based on the elementary theory of the method primarily due to NORTHRUP and ANSON[19] and to MCBAIN and LIU,[16] GORDON[11] has given the following general equation for evaluating the diffusivities of solutes in liquids:

$$\ln \frac{\Delta C_f}{\Delta C_o} = -\beta Dt$$

This integrated form of the equation is applicable in cases where the concentration gradient across the diaphragm changes continuously during an experiment, and BARNES[2] has shown that this equation is rigorous for cells in which the volume of solutions in comparison with the volume of diaphragm is large. Since these conditions are satisfied in the course of the experiments reported in this paper, GORDON'S equation mentioned above was used to calculate the diffusivities. The cell factor was initially determined by studying the diffusion of potassium chloride from 0.1N aqueous solution into water at 25°C, using the diffusivity given by GORDON[11] for this particular system. During sub-

TABLE I—Properties of Acids

Acid	Formula Weight MB	Weighted mol. volume VB	Melting Point °C	Density 25/4 gm/cc
Acetic	60.05	68.4		1.0493
n-Propionic	74.08	90.6		0.9882
n-Butyric	88.10	112.8		0.9551
n-Valeric	102.1	135.0		0.9440
Oxalic	90.0	85.0	189.0	
Citric	192.1	202.4	153.0	
Benzoic	122.1	149.8	122.5	
Salicylic	138.1	161.8	159.0	
Cinnamic	148.2	186.8	133.5	
Stearic	284.5	423.6	69.0	

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sequent runs, studies were made on the diffusion of various organic acids from 0.01N solutions in ethanol-water mixtures of different compositions into the same solvent mixture as that in which the initial acid solution was prepared. Every diffusion run was generally of 24 hr duration or more, and the determinations were made at 25 ± 1°C. For the cell used, the cell factor was 0.0889 cm^{-2}.

By the application of the kinetic theory of gases to liquids[1] and from the standpoint of the theory of absolute reaction rates[7] equations have been proposed to estimate diffusivities of solutes in pure single solvents. Based on the STOKES-EINSTEIN equation, an empirical correlation[21] has also been reported for the diffusion of solutes in water, methyl alcohol and benzene. Results obtained in the present investigations are given in Table III. Attempts were made to correlate these data to yield a general expression, and the following equation was found to be most satisfactory:

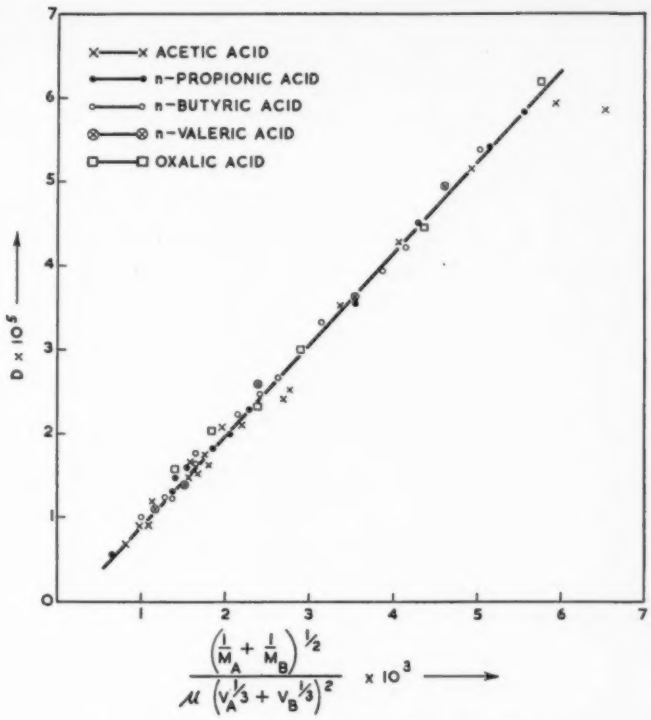
$$D = 0.0104 \frac{1}{(\mu V_A^{\frac{1}{3}} + V_B^{\frac{1}{3}})^2} \left(\frac{1}{M_A} + \frac{1}{M_B}\right)^{\frac{1}{2}}$$

The validity of the above expression is obvious from a reference to the accompanying figure in which the results are suitably plotted. The empirical coefficient of the proposed equation was determined from the slope of the best straight line drawn by eye, and it is observed that the slope in this case is of the same order as that of ARNOLD'S relation[1] for diffusion in pure solvents.

TABLE II—Properties of Ethanol-water Mixtures

Volume % Ethanol	Mole Fraction Ethanol	Weighted mol. wt.	Weighted mol. volume	Viscosity* at 25°C centipoises
0	0	18.0	14.80	0.96
10	0.0330	18.93	16.27	1.00
20	0.0714	20.00	17.97	1.14
30	0.1164	21.27	19.97	1.33
40	0.1701	22.78	22.36	1.53
50	0.2353	24.61	25.25	1.80
60	0.3157	26.87	28.83	2.08
70	0.4178	29.72	33.36	2.30
80	0.5514	33.49	39.28	2.38
90	0.7343	38.63	47.40	2.11
100	1.000	40.07	59.20	1.10

* Obtained by interpolation of data given in International Critical Tables.



Comparison of experimentally observed diffusivities with those calculated by proposed correlation.

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ACKNOWLEDGMENT

The author is obliged to PROFESSOR A. I. JOHNSON of the University of Toronto, Toronto, Canada, for suggesting this problem and for providing the necessary facilities to carry out these investigations.

Symbols Used

ΔC_f = difference in solute concentrations in the two compartments of the cell at the end of a run;
ΔC_o = difference in solute concentrations in the two compartments of the cell at the beginning of a run;
D = diffusivity, cm^2/sec;
M_A = weighted molecular weight of solvent mixture;
M_B = weighted molecular weight of diffusing acid;
V_A = weighted molecular volume of solvent mixture;
V_B = weighted molecular volume of diffusing acid;
t = duration of a run, sec;
β = cell factor, cm^{-2};
μ = viscosity of the solvent mixture, centipoises.

TABLE III—Diffusivities of Organic Acids in Ethanol-water Mixtures

Volume % Ethanol	Diffusivity × 10^5, cm^2/sec, of the acid									
	Acetic	n-Propionic	n-Butyric	n-Valeric	Oxalic	Citric	Benzoic	Salicylic	Cinnamic	Stearic
0	5.80	5.85	5.32	4.90	6.10	4.15				
10	5.91	5.40								
20	5.09	4.45	3.90	3.55	4.42	3.35				
30	4.17	3.50								
40	3.48	2.95	2.62	2.55	3.00	2.00				
50	2.39	2.27								
60	2.11	1.85	1.65	1.40	2.05	1.20				
70	1.76	1.60								
80	1.49	1.30	1.20	1.05	1.50	1.00				
90	1.67	1.42								
100	2.48	2.42	2.20	2.05	2.30	1.75	1.65	0.70	1.60	1.15

658.32

PART II

THE STATUS AND REMUNERATION OF THE PROFESSIONAL MAN IN INDUSTRY

Equations are derived to show how remuneration and status vary with age and with time, allowing also for economic factors. Economic indices are used to illustrate the changing pattern of the national economy and the equations are further developed in terms of such indices. What the individual experiences and feels to be taking place differs from what is taking place, and separate equations are derived for the two cases

by M. DAVIDMANN

Remuneration Mathematics

THE remuneration received by a professional employee from full-time employment may be determined from:

$$Y_r = y_{0r}\, e^{-(X_r - x_{or})^2/b_r} \qquad \ldots.(5)$$

The suffix r indicates his remuneration in the reference year T_r. The constant b is determined by the individual's group. His grade G within the group determines x_0 and y_0, X being the age of the individual during the year being considered. b, G, x_0 and y_0 may be determined from remuneration surveys; that is, from the national remuneration scale for the reference year.

The remuneration received in any year T_n is given by:

$$Y_n = y_{0n}\, e^{-(X_n - x_{on})^2/b_n} \qquad \ldots.(6)$$

Consider that the remuneration of the individual's grade is increasing at $100i_p$ per cent compound interest per year, this increase being caused solely by economic factors. Then

$$y_{0n} = y_{0r}\,(1 + i_p)^{T_n - T_r} \qquad \ldots.(7)$$

so that

$$Y_n = y_{0r}\,(1 + i_p)^{T_n - T_r} e^{-(X_n - x_{on})^2/b_n} \qquad \ldots.(8)$$

When the x_0 distributions and the constant b do not alter appreciably with time for the particular group, as was shown to be the case for chemists, we have for the particular individual and for his grade:

$$Y_r = y_{0r}\, e^{-(X_r - x_o)^2/b} \qquad \ldots.(5a)$$

and

$$Y_n = y_{0r}\,(1 + i_p)^{T_n - T_r} e^{-(X_n - x_o)^2/b} \qquad \ldots.(8a)$$

But, for a single individual:

$$X_n = X_r + (T_n - T_r)$$

and

$$T_n - T_r = X_n - X_r$$

Hence, in terms of time:

$$Y_n = y_{0r}\,(1 + i_p)^{T_n - T_r} e^{-(X_r + T_n - T_r - x_o)^2/b} \qquad \ldots.(8b)$$

and, in terms of age:

$$Y_n = y_{0r}\,(1 + i_p)^{X_n - X_r} e^{-(X_n - x_o)^2/b} \qquad \ldots.(8c)$$

It should be particularly noted that Equations (8b) and (8c) apply only to a single individual.

Equation (8), in any of its forms, gives the iso-grade lines for individuals. The remuneration of a professional employee increases in accordance with this equation as long as he receives neither promotion nor demotion, that is as long as he remains in his particular grade. The equation gives the remuneration he receives as he grows older and is here referred to as the "dynamic iso-grade" remuneration equation. Equation (5) or (6), however, gives the remuneration of individuals of different ages, of the same grade, at a particular time, and is referred to here as the "static iso-grade" remuneration equation. Equations (5), (6) and (8), in their various forms, apply to professional employees.

The fully trained manual employee receives the rate for his grade, irrespective of age and leaving out of consideration special rewards such as "fringe benefits" for long service. His remuneration depends on economic factors, but not on age. Hence

$$x_0 = X \qquad \ldots.(9)$$

so that, from Equation (5) or (6), we see that, for any particular year, and by definition:

$$E = Y = y_0 \qquad \ldots.(10)$$

Suppose that the remuneration of the manual employee's grade is increasing at rate $100i_m$ per cent compound interest per year, this change in remuneration being caused by economic factors such as altered rates and differences in hours worked. The remuneration received by a manual employee is given by:

$$E_n = E_r\,(1 + i_m)^{T_n - T_r} \qquad \ldots.(11)$$

Equation (10) is the static iso-grade equation, and Equation (11) the dynamic iso-grade remuneration equation, for manual employees.

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Status Mathematics

Status is relative and is evaluated as the ratio of remunerations. Status between individuals and thus between their grades may be evaluated as shown below.

Let S be the status between two individuals. The status of individual 1 relative to individual 2 is then given by the ratio of the remuneration received by individual 1 to that received by individual 2, denoted by S_{12}, it being convenient to arrange the ratio so that S_{12} is greater than unity.

It follows that:

$$\frac{S_{13}}{S_{23}} = S_{12} \qquad \ldots.(12)$$

The relations developed below apply equally to individuals in different grades within the same group as to individuals and their grades from different groups.

Static status is that between individuals and their grades in any particular year. The static status equations developed here show how status varies with age for individuals in the grades being considered, in a particular year.

For static status between professional employees, from Equation (5a) we have:

$$S_{12r} = \frac{Y_{1r}}{Y_{2r}} \qquad \ldots.(13)$$

$$= \frac{(y_{0r}\, e^{-(X_r - x_0)^2/b})_1}{(y_{0r}\, e^{-(X_r - x_0)^2/b})_2} \qquad \ldots.(14)$$

By definition the static status of manual employees relative to each other is given by:

$$S_{12r} = \frac{E_{1r}}{E_{2r}} \qquad \ldots.(15)$$

Similarly, the static status between professional and manual employees is:

$$S_{12r} = \frac{Y_{1r}}{E_{2r}} \qquad \ldots.(16)$$

$$= \frac{(y_{0r}\, e^{-(X_r - x_0)^2/b})_1}{E_{2r}} \qquad \ldots.(17)$$

The dynamic status equations show how status changes as the individual grows older, assuming that he remains in his grade, receiving neither promotion nor demotion. These dynamic status equations show the status changes which the individual feels are taking place as he grows older and thus portray his own progress as he sees it.

The dynamic status between professional employees, from Equation (8a), is:

$$S_{12n} = \frac{Y_{1n}}{Y_{2n}} \qquad \ldots.(18)$$

$$= \frac{(y_{0r}\,(1 + i_p)^{T_n - T_r}\, e^{-(X_n - x_0)^2/b})_1}{(y_{0r}\,(1 + i_p)^{T_n - T_r}\, e^{-(X_n - x_0)^2/b})_2} \qquad \ldots.(19)$$

The dynamic status of manual employees with respect to each other, from Equation (11), is:

$$S_{12n} = \frac{E_{1n}}{E_{2n}} \qquad \ldots.(20)$$

$$= \frac{(E_r\,(1 + i_m)^{T_n - T_r})_1}{(E_r\,(1 + i_m)^{T_n - T_r})_2} \qquad \ldots.(21)$$

Similarly, the dynamic status of professional relative to manual employees is given by:

$$S_{12n} = \frac{Y_{1n}}{E_{2n}} \qquad \ldots.(22)$$

$$= \frac{(y_{0r}\,(1 + i_p)^{T_n - T_r}\, e^{-(X_n - x_0)^2/b})_1}{(E_r\,(1 + i_m)^{T_n - T_r})_2} \qquad \ldots.(23)$$

The use of these equations is straightforward. For example, Equation (19) may be used to compare different grades within one profession or the same grades in different professions, to see how individuals feel their own progress. Equation (17) may be used for comparing professional employees with manual employees for a particular year. Equation (23) may be used to compare professional with manual employees to see how they feel their status changing as they grow older.

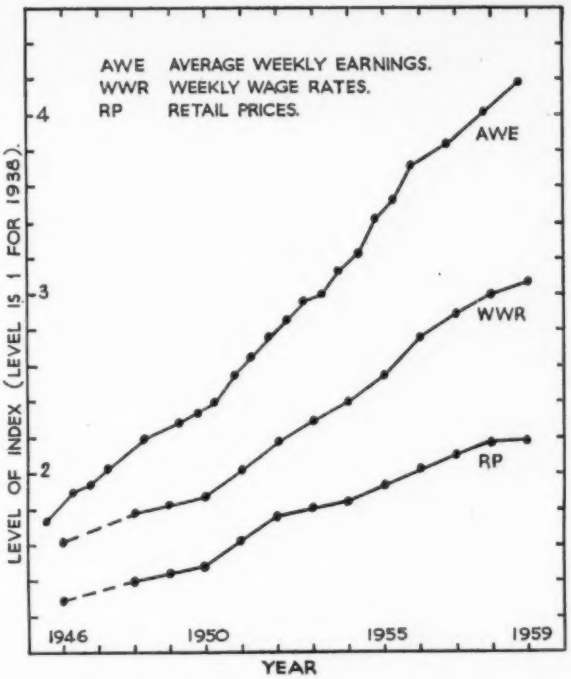

Fig. 20. Economic indices for manual employees.

So far we have set up the static status equations which show status as it exists in a particular year, and we have also established the dynamic status equations which show the changes in status which individuals feel are taking place. However, we still have to see how status actually alters with time.

Let I_{12s} be the status index, defined by the ratio S_{12n}/S_{12r}. The status at any particular year is then given as a ratio to that for the same age in the reference year, and the status index I_{12s} thus evaluates the factual changes in status which are taking place. For example, considering a particular grade in a profession and a manual employee, utilizing Equations (23) and (17), we have:

$$\text{status index} = \frac{S_{12n}}{S_{12r}} \qquad \ldots.(24)$$

$$= \frac{\dfrac{y_{0r}}{E_r}\left(\dfrac{1 + i_p}{1 + i_m}\right)^{T_n - T_r} e^{-(X_n - x_0)^2/b}}{\dfrac{y_{0r}}{E_r}\, e^{-(X_r - x_0)^2/b}}$$

$$= \left(\frac{1 + i_p}{1 + i_m}\right)^{T_n - T_r} \frac{e^{-(X_n - x_0)^2/b}}{e^{-(X_r - x_0)^2/b}} \qquad \ldots.(25)$$

Status at age X_n during year T_n has to be compared with status at age X_n during year T_r, so that

$$X_r = X_n$$

and Equation (25) becomes

$$I_{12s} = \left(\frac{1 + i_p}{1 + i_m}\right)^{T_n - T_r} \qquad \ldots.(26)$$

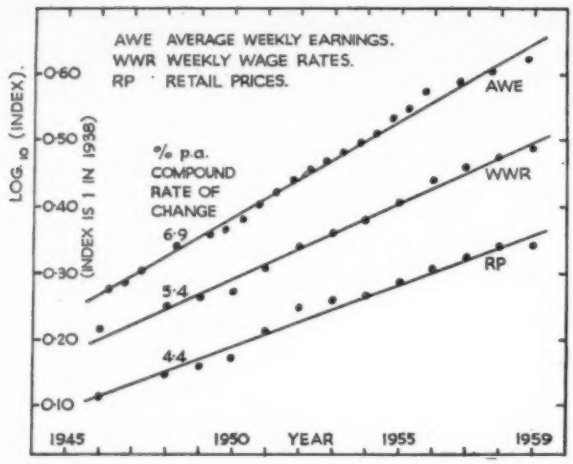

Fig. 21. Economic indices for manual employees.

Equation (26) is general and, for the general case, we have

$$I_{12s} = \left(\frac{1+i_1}{1+i_2}\right)^{T_n - T_r} \qquad \ldots.(27)$$

When the remuneration of both increases at the same percentage rate, the status of one relative to the other remains constant. When their remuneration increases at different rates, status changes, increasing or decreasing as i_1 or i_2, respectively, is the greater rate.

Knowing the rates at which remuneration is increasing, one may immediately compute gain or loss of status with Equation (27).

The status index I_{12s} is the status in the year T_n divided by what the status was in the year T_r and the status index may be interpreted as giving the status in the year T_n on the basis that the status in the year T_r was unity.

By definition

$$I_{12s} = \frac{S_{12n}}{S_{12r}}$$

so that for year T_r we have

$$I_{12s} = \frac{S_{12r}}{S_{12r}} = 1 \qquad \ldots.(28)$$

It is worth noting that

$$\frac{I_{13s}}{I_{23s}} = I_{12s} \qquad \ldots.(29)$$

Use of Indices

One may not always be justified in assuming that remuneration increases at constant or average compound interest rates, and indices can then be used to calculate the year-by-year changes.

For professional employees consider two successive remuneration surveys, one taken in year T_r and the other in year T_n:

$$Y_r = y_{0r}\, e^{-(X_r - x_0)^2/b} \qquad \ldots.(5a)$$

$$Y_n = y_{0n}\, e^{-(X_n - x_0)^2/b} \qquad \ldots.(5b)$$

so that

$$\frac{Y_n}{Y_r} = \left(\frac{y_{0n}}{y_{0r}}\right)\left(\frac{e^{-(X_n - x_0)^2/b}}{e^{-(X_r - x_0)^2/b}}\right) \qquad \ldots.(30)$$

The remuneration index for professional employees, I_p, should be a measure of changes in remuneration due to economic conditions. It thus has to be a ratio which is independent of the position of the individual, as this changes with his age, so that remuneration at age X_n during year T_n has to be compared with remuneration received by an individual of the same age but during year T_r. Hence

$$X_n = X_r$$

and Equation (30) becomes

$$\left(\frac{Y_n}{Y_r}\right)_X = \frac{y_{0n}}{y_{0r}}$$

so that we define

$$I_p = \left(\frac{Y_n}{Y_r}\right)_X = \frac{y_{0n}}{y_{0r}} \qquad \ldots.(31)$$

Note that

$$y_{0n} = y_{0r}\,(1 + i_p)^{T_n - T_r} \qquad \ldots.(7)$$

so that

$$I_p = \frac{y_{0n}}{y_{0r}} \qquad \ldots.(32a)$$

$$= (1 + i_p)^{T_n - T_r} \qquad \ldots.(32b)$$

Note that, from Equation (30), we have

$$Y_n = \left(\frac{y_{0n}}{y_{0r}}\right)\left(\frac{e^{-(X_n - x_0)^2/b}}{e^{-(X_r - x_0)^2/b}}\right)(Y_r)$$

$$= (I_p)\left(\frac{e^{-(X_n - x_0)^2/b}}{e^{-(X_r - x_0)^2/b}}\right)(Y_r) \qquad \ldots.(33)$$

and also that

$$I_p = \left(\frac{Y_n}{Y_r}\right)\left(\frac{e^{-(X_r - x_0)^2/b}}{e^{-(X_n - x_0)^2/b}}\right) \qquad \ldots.(34)$$

Equation (33), which corresponds to Equation (8a), is used to calculate or predict an individual's remuneration when I_p is known, say from two successive surveys which gave y_{0r} and y_{0n}. The career earnings ratio for the grade for the two surveys also gives the y_0-ratio in Equation (31).

Symbols Used

b = constant, defining the distribution of remuneration with age, for a particular group or subgroup;
i = rate of change, per cent compound rate of change per year, generally expressed as a fraction;
x_0 = age at which remuneration is a maximum, for a particular grade;
y_0 = maximum level of remuneration, at age x_0;
C = career or mean career earnings (£);
E = remuneration received by manual employee during one year, preferably the fiscal year (£);
G = fraction (per cent) = grade. For example, $G75$ = grade 75 per cent when fraction = 75 per cent.
I = index, preferably used on the basis that $I = 1$ in the reference year.
S = status, that is remuneration ratio;
S_{12} = status, ratio of remuneration of subject "1" to subject "2", with S_{12} preferably ≥ 1.
T = time, that is year, for example: 1960. Either fiscal or calendar year, preferably fiscal year;
X = age (years);
Y = remuneration received by professional employee during one year, preferably the fiscal year (£).

Suffixes

g = grade;
m = manual employee;
n = any particular year;
p = professional employee;
r = reference year, for example year to which survey refers or in which a particular index is 1;
s = status;
R = reference year of economic index;
X = at constant age.

i_p may also be estimated from other data relating to, for example, cost of living. Equation (34) enables one to separate, for a particular individual, that part of any change of remuneration which corresponds to the changing economic situation.

For the manual employee, let I_m be an index which estimates the remuneration he receives. It is defined as the ratio of remuneration received in any particular year to that in a specific reference year. Let the reference year on which this index is based be denoted by the suffix R. Hence, by definition, we have:

$$I_{mn} = \frac{E_n}{E_R} \qquad \ldots.(35)$$

and

$$I_{mr} = \frac{E_r}{E_R} \qquad \ldots.(36)$$

so that

$$\frac{E_n}{E_r} = \frac{I_{mn}}{I_{mr}} \qquad \ldots.(37)$$

and

$$E_n = \frac{I_{mn}}{I_{mr}} E_r \qquad \ldots.(38)$$

Equations (37) and (38) apply as long as the basic reference year T_R on which the index is based remains the same. Where T_R for an index changes during the period under consideration, the index has to be recalculated to satisfy this condition before Equations (37) and (38) can be used.

Note that

$$E_n = E_r\,(1 + i_m)^{T_n - T_r} \qquad \ldots.(11)$$

so that, from Equation (38), we have

$$\frac{I_{mn}}{I_{mr}} = (1 + i_m)^{T_n - T_r} \qquad \ldots.(39)$$

Equations (32b), (38) and (39) enable one readily to restate the previously derived equations in terms of remuneration and economic indices. For example, the status index I_{pms} may be derived from Equation (27), thus:

$$I_{pms} = \left(\frac{1 + i_p}{1 + i_m}\right)^{T_n - T_r}$$

$$= (I_p)\left(\frac{I_{mr}}{I_{mn}}\right) \qquad \ldots.(40)$$

Grades within one group of professional employees may be compared with each other and with manual employees by the equations given so far, but career earnings could be used equally well, when available, in the same way as described below for mean career earnings. However, mean career earnings have to be used when comparing different groups, such as professions, with each other. Calculations based on mean career earnings may be carried out on the following basis:

$$S_{12r} = \frac{C_{1r}}{C_{2r}} \qquad \ldots.(41)$$

and

$$S_{12n} = \frac{C_{1n}}{C_{2n}} \qquad \ldots.(42)$$

so that

$$I_{12s} = \frac{S_{12n}}{S_{12r}} \qquad \ldots.(43)$$

$$= \frac{C_{1n}}{C_{1r}} \Big/ \frac{C_{2n}}{C_{2r}} \qquad \ldots.(44)$$

But

$$\frac{C_n}{C_r} = (1 + i)^{T_n - T_r} \qquad \ldots.(45)$$

and again we see that

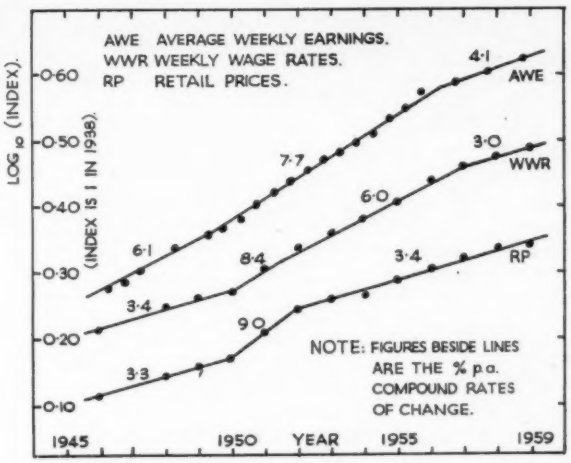

Fig. 22. Economic indices for manual employees.

$$I_{12s} = \left(\frac{1 + i_1}{1 + i_2}\right)^{T_n - T_r} \qquad \ldots.(27)$$

Equations (32b) and (39) may be applied when calculations in terms of indices are to be carried out.

The Changing Pattern of the Economy

Economic indices portray the changing pattern of the economy and may be used to illustrate it, bearing in mind their limitations. The indices used here are those collected and published by the Central Statistical Office,[9] indicating changes in average weekly earnings, in weekly wage rates and in retail prices.

The index of retail prices is a measure of the cost of living. It measured,[10] up to 1956, changes in the average level of prices for goods and services required by working-class families, but from 1956 onwards by practically all wage earners and most small and medium salary earners. The index used here is that for all the items that go to make it up. One may regard such changes in composition of the index as reflecting changes in the pattern of expenditure rather than fundamental changes of the index. As the pattern of expenditure alters, so in due course the index is adjusted as well.

The index of weekly wage rates[10] is a measure of the level of full-time weekly wage rates for manual employees in 80 industries and services. Piece-work rates as well as time rates are included. The index used here is that for all workers and all industries and services.

The index of average weekly earnings[10] is a measure of the combined effect of changes in overtime rates and hours worked as well as wage rates, but is also dependent on the distribution of workers amongst the industries concerned, and on the composition of the working population with respect to age and sex. The index used here is that for all operatives and all industries.

It is seen from the way in which the indices were selected that we are here concerned with illustrating a general case with what information is available, rather than with calculating more exact data for a particular industry. Indices are linked without regard to changes in composition, such changes being taken to accord with the changing economic pattern. We are concerned with rates of change rather than with actual levels, and such rates are independent of the way in which the indices are linked or of the reference year on which the index is based. The indices used here were linked and recalculated to the reference year 1938. They are illustrated by Fig. 20, which shows the three indices with which we are concerned, recalculated on the basis that the index is 1 in each case for the year 1938.

Changes occur on the basis of the pattern at the time rather than on the pattern as it was in an arbitrary reference year. Hence indices change in each year, this change being based on the level of the index obtaining at the time rather than the level in the reference year. The indices thus advance in accordance with the compound interest law. This may be illustrated by plotting the logarithm of the index against time, when the gradient of the line joining any two points measures the compound rate of change between them. Fig. 21 shows the indices plotted in this way. For the period 1946-59, for the manual employee, prices increased at about 4.4 per cent, wage rates at about 5.4 per cent and remuneration at about 6.9 per cent, these being compound rates of change. The standard of living of the manual employee, as judged by remuneration, thus increased at about 2.5 per cent compound rate of change per year.

The compound rates of change are, however, more accurately represented as illustrated by Fig. 22, which is of interest when considering the more immediate past. During the period 1952-56 prices increased by about 3.4 per cent, wage rates by about 6.0 per cent, remuneration by about 7.7 per cent and standard of living by about 4.3 per cent, these being compound rates of change per year. More recently, since 1956, prices have increased at about the same rate as before, but wage rates increased at about 3.0 per cent p.a., remuneration at about 4.1 per cent p.a. and standard of living at about 0.7 per cent p.a.

For ease of reference, the compound rates of change, in per cent per year, are given below in the form of a table:

Period	Prices	Wage Rates	Earnings
1952–56	3.4	6.0	7.7
1956–59	3.4	3.0	4.1
1946–59	4.4	5.4	6.9

The References to this article were published with Part 1 (July).

Developments of the Scandinavian Chemical Industry

Inorganic Chemicals

THE production of inorganic chemicals in Scandinavia is, with the exception of fertilizers, tied up with the cellulose industry. Further expansion is expected in the 1960s in the production of chemicals such as chlorine and alkalis, sodium sulphate and sodium chlorate. This is also the case with hydrogen peroxide, which is replacing chlorine dioxide as a bleaching agent for pulp.

With the increased production of sodium sulphate, more sulphuric acid must be produced to keep up with the demand. Sulphuric acid also plays a vital role in new industries, such as the Swedish uranium production and the Finnish titanium dioxide plant, the first of its kind in Scandinavia.

Sweden exports arsenic trioxide and selenium, and these industries are now being modernized and extended. The Swedish Superphosphate Co. intend to enter the world market in competition with the old-established superphosphate-exporting countries of Holland and Belgium.

Several plans are currently being investigated for exploiting some remarkably abundant salt deposits in Denmark.

Some interesting developments are taking place in the Scandinavian nitrogen industry. Norwegian Hydro, one of the world's largest exporters of nitrogen products, manufacture about 300,000 tons/year of nitrogen as primary ammonia. This quantity will be stepped up with increased energy resources. In addition, the Norwegians are planning to build an ammonia plant of 50,000 tons/year, based on coke furnace gases.

An ammonia plant built in 1952 by the Finnish Government has been pioneering the manufacture of synthesis gas from inferior fuel. Bunker oil, the cheapest fuel oil, has been utilized for several years, and the technical difficulties encountered have been overcome. The capacity of this plant is to be increased by another 50 per cent in order to supply most of the country's demand.

Denmark so far has imported all her nitrogen, some 123,000 tons/year, mostly from Norway. The Danes, however, have plans to cut this import by building their own ammonia plant. This plant will have a capacity of 30,000 tons/year of nitrogen based on bunker oil.

The consumption of nitrogen fertilizers in Sweden during the last ten years has increased from 60,000 to more than 100,000 tons/year. About two-thirds of this quantity is imported, mainly from Norway. This import will decrease with the commissioning of Swedish Shale Oil's new ammonia plant of 22,000 tons/year.

A large steel plant was built in the northern part of Norway after the war, though latterly the main effort has been concentrated on developing the aluminium industry. The Norwegian production of aluminium has almost doubled in five years to nearly 200,000 tons/year and is expected to expand at the same rate. This has been made possible thanks to cheap hydroelectric power and foreign capital. Norwegian Hydro, already the largest producer of magnesium in Western Europe, has also decided to enter the aluminium industry. Accordingly, hydro-electric schemes are planned in the West of Norway corresponding to an aluminium production of 100,000 tons/year.

Organic Chemicals

Swedish Esso are building a cracking plant which is expected to be ready by July 1, 1963. The raw material will be naphtha and the main products ethylene and propylene. A distillate, which is excellent as a petrol additive, and a fuel oil of high quality are obtained as by-products. The process consists of a short, drastic cracking at 670-690°C in the presence of hydrogen. The products are cooled in a few seconds by injecting a petroleum distillate, and are subsequently fractionated by distillation. The main products, which are gaseous olefins, are processed further in separate plants connected to the cracking plant by pipelines. Swedish Esso are to build one of these plants to make polypropylene from propylene. Two other plants will take care of the ethylene, part of which will be oxidized by air to yield ethylene oxide for manufacturing ethylene glycol.

Sweden and Norway are planning a strong expansion of their PVC production, the targets being 25,000 and 20,000 tons/year respectively. In order to obtain the raw material for this production, acetylene, large carbide furnaces are to be built in Finland and Norway. By altering present plants, Sweden has mandated to increase the capacity of her carbide furnaces by more than 20 per cent.

A plant is planned in Sweden for the production of LD-polyethylene, the soft polyethylene which now has 80-85 per cent of the market. The experience of Union Carbide in this field will be available to produce a great variety of polyethylene products.

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PART III

SURVEY OF DIGITAL COMPUTER APPLICATIONS IN THE UNITED STATES

by J. J. TABOREK

Design and Performance Evaluation of Heat Exchangers

The heat exchanger is a very universally used equipment requiring frequently repeated and tedious calculations. Heat exchangers were, therefore, among the first equipment design programmes developed for computers. The usefulness of a heat exchanger programme will be realized particularly if the programme will be as general as practicable. The various problem types will include:

(a) Construction types: Double pipe exchangers, shell and tube exchangers and air coolers, using plain, radially or longitudinally finned tubes.

(b) Operations: No phase change; condensation in horizontal or vertical units with eventual desuperheating or subcooling; condensation of vapour-gas mixtures; vaporization.

(c) Problem formulation: Performance evaluation of equipment of known dimensions with respect to maximum fouling or other parameters; design for number of units of given characteristics (used preferably for double pipe exchangers); design to engineering specifications; design for economic optimum with respect to various parameters (flow velocity; outlet temperature).

Practically all combinations between these possibilities are used.

The more complete and automated a programme is, the more efficient it will be for the engineer to use, without spending time in checking the applicability of his case to the available programme. Another advantage of a complete programme is that all cases can be evaluated by the same methods.

The calculation time for an optimized design of a heat exchanger will be about six minutes on the medium speed magnetic drum computers and about 30 seconds on the high speed machines.

The method of problem attack by computers is quite different from manual methods.[15] The important points shall be explained on the specific case of design for shell and tube exchangers.

1. Data and Optional Parameters

The programme will require that the tube size and the layout pattern be specified. Optional limitations include the maximum shell diameter, maximum tube length, number of shell passes and number of tube passes. The calculation is based on the specified maximum flow velocity and/or pressure drop of both streams.

2. Mathematical Solution Methods

Present manual solution methods make use of various graphical and tabular aids. For computer use such information must be translated into equation forms of possibly general applicability. A few important subjects along these lines will be explained in the following examples:

(a) Correction factor to the mean log. temperature difference of multipass units is usually taken from diagrams (e.g., VDI Waermeatlas p. Ca 6). For computer use an equation of general validity can be developed.[18] For the correction factor F:

$$F = \frac{\sqrt{R^2+1}}{R-1} \cdot \frac{\ln\left[\dfrac{1-P_x}{1-R\,P_x}\right]}{\ln\left[\dfrac{\dfrac{2}{P_x}-1-R+\sqrt{R^2+1}}{\dfrac{2}{P_x}-1-R-\sqrt{R^2+1}}\right]} \qquad \ldots.(1)$$

where:

$$P_x = \frac{1-\left[\dfrac{RP-1}{1-RP}\right]^{\frac{1}{\psi}}}{R-\left[\dfrac{RP-1}{1-RP}\right]^{\frac{1}{\psi}}} \qquad \ldots.(2)$$

$$P = \frac{t_2-t_1}{T_1-t_1} \qquad \ldots.(3)$$

$$R = \frac{T_1-T_2}{t_2-t_1} \qquad \ldots.(4)$$

and ψ is the total number of shell passes.

$$\psi = N \,.\, N_{sp} \qquad \ldots.(5)$$

In performance evaluation of a given unit, the equations are simply solved for F. For design of a new system, equation (1) is solved while assuming $\psi = 1, 2, 3 \ldots$ until a value of F is reached, larger than an assumed F — minimum, (usually 0.75).

If $R = 1$, equation (1) becomes indeterminate

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and the alternate solution applies:

$$F = \frac{\dfrac{P_x\sqrt{R^2+1}}{1-P_x}}{\ln\left[\dfrac{\dfrac{2}{P_x}-1-R+\sqrt{R^2+1}}{\dfrac{2}{P_x}-1-R-\sqrt{R^2+1}}\right]} \quad \ldots.(6)$$

with

$$P_x = \frac{P}{\psi - \psi P + P} \quad \ldots.(7)$$

(b) The heat transfer coefficients follow particular equations for laminar (Re < 2000) and turbulent (Re > 10,000) flow. For the intermediate flow the values are usually taken from graphical solution sheets. For computer use it is recommended that the coefficient in the mixed region (2000 < Re < 10,000) be calculated by interpolation between the laminar value α_{lam} (at Re = 2000) and the turbulent value α_{turb} (at Re = 10,000),

$$\alpha = [\alpha_{turb} - \alpha_{lam}]\frac{\mathrm{Re} - 2000}{8000} + \alpha_{lam} \quad \ldots.(8)$$

(c) Condensing coefficients must be evaluated for horizontal and vertical units with condensation outside or inside of plain or finned tubes. The "condensate tube loading" type equation appears definitely preferable for machine calculations. In the development of the equation the tube loading term $(W_c/L\,N_t)$ (i.e., the condensate flow W_c (lb/h) per longitudinal ft of one tube) was used for all types of condensation and an additional term (A_e/P) was introduced as the ratio of the effective condensation surface per foot of tube length to a characteristic parameter P.

Horizontal Condensers

Nusselt's equation for horizontal tubes:

$$\alpha = 0.725\left[\frac{k_f\,\rho_f{}^2\,g}{\mu_f\,D\,\Delta t_{cf}}\right]^{\frac{1}{4}} \quad \ldots.(9)$$

The total heat transferred can be expressed as:

$$Q = \lambda W_c = \alpha\, A_e\, L\, N_t\, \Delta t_{cf}$$

From this equation, the term $\dfrac{\lambda}{\Delta t_{cf}}$ can be calculated:

$$\frac{\lambda}{\Delta t_{cf}} = \alpha\, A_e \frac{L\,N_t}{W_c} \quad \ldots.(10)$$

Combining now both Eq. (9) and (10) and considering D as a flow parameter P:

$$\alpha = 0.65\left[\frac{k_f{}^3\,\rho_f{}^2\,g}{\mu_f}\right]^{\frac{1}{4}}\left[\frac{A_e}{P}\frac{L}{W_c}\frac{N_t}{}\right]^{\frac{1}{4}} \quad \ldots.(11)$$

For plain tubes, outside condensation, $A_e = \pi\, D_0$ and $P = D_0$. With these substitutions, Eq. (11) will transit into the form familiar from pertinent literature (Ref. 19).

For radially finned tubes, A_e is the total finned area per ft length adjusted for the fin efficiency:

$$A_e = A_{eq} = \eta\, A_f + A_r \quad \ldots.(12)$$

Computation of the effective equivalent diameter D_{eq} is based on Ref. 20:

$$P = D_{eq} = D_r\, H_m\left[\frac{\eta_i\, A_f + A_r}{A_r\, H_m{}^{\frac{1}{2}} + 1.3\,\eta_i\, A_f\, D_r{}^{\frac{1}{2}}}\right]^4 \quad \ldots.(13)$$

where H_m is the mean effective fin height (ft) defined as:

$$H_m = \frac{\pi}{48}\frac{(d_{0f}{}^2 - d_r{}^2)}{d_{0f}}$$

The above equations were developed only for single tubes. The downflow of the condensate in a vertical tube row causes first the film resistance to increase and then, eventually, to decrease again as the flow becomes turbulent.[11] In the usual form of industrial heat exchangers using circular tube bundles, the length of the vertical tube rows varies. The overall coefficient can then be calculated as

$$\alpha_{av} = \frac{2\sum_{i=0}^{i=x}\alpha_{ri}\,n_i}{2\sum_{i=0}^{i=x} n_i} \quad \ldots.(14)$$

when α_{ri} is the average coefficient for the ith row
n_i is the number of tubes in the ith row
The factor 2 indicates that the evaluation is for a half circle starting with the first row off the centre with symmetry line unoccupied.

The row-average coefficient α_{ri} can be expressed by the single tube coefficient α as:

$$\alpha_{ri} = \alpha n_i{}^{-\frac{1}{s}} \quad \ldots.(15)$$

There is experimental evidence that s will have the value of about 6.[10] Combining equation (14) and equation (15) we get:

$$\alpha_{av} = \alpha\left[\frac{\sum_{i=0}^{i=x} n_i{}^{\frac{s-1}{s}}}{\sum_{i=0}^{i=x} n_i}\right] \quad \ldots.(16)$$

The expression in parenthesis can be considered a multi-tube correction factor C_t. Its evaluation on a digital computer is extremely simple. The chord length of each tube row is calculated and divided by the corresponding dimension of the layout pattern, delivering n_i for each row.

Vertical Condensers

For vertical condensers the Nusselt's equation is:

$$h = 0.943\left[\frac{k_f{}^3\,\rho_f{}^2\,g}{\mu_f\,L\,\Delta t_{cf}}\right]^{\frac{1}{4}} \quad \ldots.(17)$$

Substituting Eq. (10) but retaining the tube loading term $\dfrac{W_c}{L\,N_t}$ we get:

$$h = 0.925\left[\frac{k_f{}^3\,\rho_f{}^2\,g}{\mu_f}\right]^{\frac{1}{4}}\left[\frac{A_e}{P}\frac{L}{W_c}\frac{N_t}{}\right]^{\frac{1}{4}} \quad \ldots.(18)$$

which is a form similar to the horizontal equation (11). The flow parameter P equals for all vertical condensers L and $A_e = \pi D_0$ for outside and $A_e = \pi D_i$ for inside condensation. With these substitutions equation (18) will transit again into the form familiar from publications. This development is, however, applicable only to laminar flow of the condensate. As shown in McAdams "Heat Transfer" book Figs. 13-6, if turbulent condensate flow occurs, the film coefficient will follow the equation:

$$\alpha\left[\frac{\rho_f{}^2}{k_f{}^3\,\mu_f{}^2\,g}\right]^{\frac{1}{3}} = 0.0077\left[\frac{4\,\Gamma}{\mu}\right]^{0.4} \quad \ldots.(19)$$

where $\Gamma = \dfrac{W_c}{\pi\, D\, N_t}$ and $\dfrac{4\,\Gamma}{\mu}$ is a pseudo-Reynolds number Re_p. The turbulent transition will take place at about $\mathrm{Re}_p = 1800$. The same source shows evidence that equation (18) for laminar condensate flow gives rather low

Symbols Used

A_i = inside tube surface per ft of tube length (ft^2/ft);
A_e = effective surface per ft tube length (ft^2/ft);
A_{eq} = equivalent effective area of radially finned tube; (ft^2/ft);
A_f = finned area per ft of tube length (ft^2/ft);
A_o = outside tube area per ft of tube length (ft^2/ft);
A_r = fin root area per ft of tube length (ft^2/ft);
D = total moles of distillate;
D_e = effective diameter (ft);
D_{eq} = equivalent diameter of radially finned tube (ft);
F = multipass correction factor;
f = total moles of component i in feed;
g = gravitation constant (ft/h^2);
H_m = mean effective fin height;
k, k_f = conductivity (subscript f for condensing film) (Btu/h ft °F);
L = length of flow path (ft);
N = number of units in series;
N_{sp} = number of shell passes;
N_{tp} = number of tube passes;
N_f = number of radial fins per in. length (1/in.);
N_t = number of tubes in shell;
p = tube layout pitch (in.);
P = flow perimeter (ft);
T_1, T_2 = hot stream temperatures in and out (°F);
t_1, t_2 = cold stream temperatures in and out (°F);
Δt_{cf} = temperature drop across the condensate film (°F);
W = total moles of kettle product;
W_c = condensate flow rate (lb/h);
α, α_o, α_i = film coefficient (subscript o for tube outside; i for tube inside) (Btu/h ft² °F);
λ = enthalpy (Btu/lb);
(cP);
μ or μ_f = viscosity (subscript f is for condensate film)
η = fin surface efficiency;
ρ or ρ_f = mass density (subscript f for condensate film).

α-values and recommends using a constant of 1.2 instead of 0.925. Rearranging equation (19) into a form showing similarity with our previous equations:

$$\alpha = 4.0 \frac{(k_f{}^2 \rho_f{}^2)^{\frac{1}{3}}}{\mu_f \, 1.07} \left[\frac{A_e}{P} \frac{L}{W_c} \frac{N_t}{W_c}\right]^{-0.4} \quad \ldots.(20)$$

where $P = L$.

For computer use, a common equation for condensation coefficient can be formulated from equation

$$\alpha = C \, C_t \, k_f \frac{\rho_f{}^{0.667}}{\mu_f{}^x} \left[\frac{A_e}{P} \frac{L}{W_c} \frac{N_t}{W_c}\right]^q \quad \ldots.(21)$$

where the parameters C, C_t, x, and P, A_e and q are selected for each case, based on simple computer logic decisions.

Overall Heat Transfer Coefficient

The following equation will be applicable to all possible cases and particularly suitable for computer applications:

$$\frac{1}{U} = \left[\frac{1}{\alpha_o} + R_0\right] + \left[\frac{1}{\alpha_i} + R_i \frac{A_0}{A_i}\right] + R_c + R_f \quad \ldots.(22)$$

(a) The first term is the outside film and fouling resistance.
(b) The second term is the inside film and fouling resistance recalculated to the outside surface A_o. For finned tubes A_o includes the finned and the root area.
(c) R_c is the conductivity resistance of the tube wall, which can be composed of several materials connected by a bond layer. The following equation sums all such resistances and relates them to the outside reference surface:

$$R_c = \frac{A_o}{2\pi} \left[\sum \frac{\ln \frac{d_L}{d_s}}{k} + \sum \frac{2 \, R_x}{d_x}\right] \quad \ldots.(23)$$

where d_L and d_s are the larger and smaller diameter of each material layer respectively and R_x is a layer resistance of diameter d_x.
(d) R_f is the fin resistance, which includes the fin efficiency η. For any type of finned tubes:

$$R_f = \left[\frac{1}{\alpha_o} + R_0\right] \left[\frac{1 - \eta_i}{\frac{A_r}{A_f} + \eta_i}\right] \quad \ldots.(24)$$

Further for radial fins of rectangular cross section, equations as developed in Ref. 20 can be rearranged for the most efficient use on computers:

$$\eta_i = \frac{3(1 + R_0 \, \alpha_o)}{3(1 + R_0 \, \alpha_o) + C_f \, \alpha_o} \quad \ldots.(25)$$

All geometrical fin constants are combined into C_f which remains unchanged through any one calculation:

$$C_f = \frac{(d_{0f} - d_r)^2}{24 \, k \, y} \frac{d_{0f}}{d_r} \quad \ldots.(26)$$

For longitudinal fins, the fin efficiency as substituted into equation 26 is expressed by:

$$\eta_i = \frac{\tanh \left[\frac{d_{0f} - d_r}{2}\right] \sqrt{\frac{\alpha_o}{6 \, k \, y}}}{\frac{d_{0f} - d_r}{2} \sqrt{\frac{\alpha_o}{6 \, k \, y}}} \quad \ldots.(27)$$

The values of A_r, A_f, A_0 and A_i can be readily calculated from the geometrical dimensions of any finned tube, if the following is known:

diameter over find	d_{0f}
root diameter	d_r
fin thickness	y
number of fins	N_f
fin material conductivity	k

If plain tubes are used, the R_f term becomes zero.

Tube Count Equation

The development of equations to determine the number of tubes which can be positioned in a shell is a very essential part of the computer programme. The method which we employed is based on calculating, row by row, the number of tubes which could be placed in the chord of a circle defined by the centres of extreme permissible position of outside tubes. Such circle diameter d_{0t}:

$$d_{0t} = d_s - (C_1 + d_0) \quad \ldots.(28)$$

Where C_1 represents the necessary clearance to the shell wall, somewhat depending on the shell diameter.

The chord length of the nth row:

$$S_n = 2\sqrt{h_n(d_{0t} - h_n)} \quad \ldots.(29)$$

and h_n is the height of the segment at the nth row.

Assuming symmetrical distribution of the rows with the symmetry line unoccupied, then

$$h_n = \left[\frac{d_{ot} - \frac{r}{2}}{2}\right] - \left[rn + C_2 N_h\right] \quad \ldots.(30)$$

where r is the vertical row distance and function of tube layout pattern.

n stands for the nth row considered, with centre line unoccupied and the first row to centre being the zero-th etc.

C_2 is a function of tube OD and shell OD and accounts for the space taken by horizontal partitions of tube passes.

N_h is the number of horizontal partitions.

The number of tubes in shell can then be calculated from

$$N_t = 2 \sum_{n=0}^{n=x} \frac{S_n}{p} \quad \ldots.(31)$$

where: each term $\left(\frac{S_n}{p}\right)$ must be rounded off to the next lower integer;

x is the limiting value of the row count, which will be reached if $\frac{S_n}{p} < 1$.

If vertical tube pass partition is used, equation (31) will be based on a quarter circle and becomes:

$$N_t = 4 \sum_{n=0}^{n=x} \frac{(S_n - C_2)}{2_p}$$

With proper selection of the constants, the method produces fairly accurate values of any tube size, tube passes, layout patterns and shell diameters. No doubt, more elaborate equations could be developed which will also require considerably more coding.

In the design programme, the number of tubes required is usually known from the heat balance calculation and the above equations are solved for the corresponding shell diameter. This is done by increasing d_s in the standard steps until the computed N_t is equal to, or larger than, the value required.

Equipment Cost Estimation

All the problem of economic optimization will be depending on the programme capacity to estimate the cost of the equipment designed. Correlating the cost figures into diagrams leads to a large number of curves which can be curve fitted by the least square method. This would present quite a load on the computer memory if a desirable degree of completeness should be reached. A preferable method was found to estimate the price of the single components separately, e.g. the tubes as a function of material, wall thickness, and length; the shell as function of material, operating pressure, baffles and construction type; the pump as a function of volume and pressure delivered. This way a large number of variations between the components is possible.

3. Overall Attack

In manual calculations the engineer would make a guess at the overall heat transfer coefficient, determine the unit size and then calculate the actual heat transferable. Comparing the required and the obtainable values he would make adjustments in the unit size until a solution was reached. The same method, if applied to computers, requires a very complicated logic for the size adjustments upward and downward as this can be done by manipulating the number of units in series and in parallel, shell diameter and tube length. A better computer method appears to be if the solution progress is split into three distinct parts:

(a) Data checks for existence and correct magnitude and all non-repetitive and auxiliary calculations. This can be done in the form of a "sub-routine" which can be subsequently overstored, thus saving the computer memory space.

(b) In the second part, the number of units and their arrangement will be established. The minimum number of units in series and/or the number of shell passes is derived from Eq. (1) is solved for ρ with F min assumed:

$$N_{min} = \frac{\rho}{N_{sp}} \text{ (to next higher integer)}$$

Then the maximum shell size is assumed and the heat balance transferable *vs* required is checked. The programme, of course, will adjust automatically the baffle spacing and number of tube passes in such a way that the available flow velocity is always fully utilized. If the heat transferred is less than required but the pressure drop is less than maximum, the programme adds one unit in series. If the available pressure drop was overpassed the solution requires to add a unit in parallel while resetting the number of units in series to equal N_{min}. The repeated adjustments between these calculations must eventually produce a solution for any given condition.

(c) Having established the unit arrangement, or confirmed that one unit is satisfactory, the programme will try to decrease the size of the unit diameter by steps corresponding to predetermined increments of the standardized size series. This process will be repeated until the pressure drop limitation is surpassed or the heat balance (produced *vs* required) is negative. At this point the programme will increase the unit size by one standard step to reach the final solution. Additional manipulation can be made with the tube length. Between each size change the programme automatically adjusts the baffle spacing and the number of tube passes so that the permissible pressure drop of both streams is utilized as closely as possible. Calculations for economic optimum are usually based on the following criterion: the larger the flow velocity of the streams, the smaller unit will result (due to better heat transfer) and the less will be the maintenance cost (due to lower fouling accumulation at high flow velocity) but the higher will be the cost of the pumping equipment and energy cost. Between these opposite trends must be an economic optimum. Solution of this optimum can be found by setting the differential of the corresponding cost equation to zero and solving for flow velocity by a trial and error method. Preferable method for computer use appears, however, to produce a series of complete solutions assuming various flow velocities and combining the solutions into a graphical diagram of cost *vs* flow velocity. Interpreting such a diagram under the simultaneous consideration of individual preferences and restrictions, the engineer will select the operating condition which will usually be a compromise of all these parameters.

ACKNOWLEDGMENT

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AN APPROXIMATION FOR THE LOGARITHMIC MEAN

by R. L. TAYLOR

CALCULATIONS in chemical engineering frequently involve the logarithmic mean of two quantities a and b, which is $\frac{a-b}{\ln a/b}$ or $\frac{a-b}{2.303\,(\log a - \log b)}$. In spite of its apparent simplicity, this expression is not easy to calculate and mistakes are often made in applying it. The following expression is recommended: $\sqrt[3]{a\,b\,\frac{a+b}{2}}$, which is much easier to evaluate either by slide rule or logarithms because it avoids the log-log concept.

The percentage error involved in this approximation is a function of the ratio a/b only, and is very small except for large values of a/b unlikely to be found in practice. The size of this error is indicated in the following table, which for simplicity is based on the special case where $b = 1$.

Table 1

a/b	$\frac{a+b}{\ln a/b}$	$\sqrt[3]{a\,b\,\frac{a+b}{2}}$	Percentage error
1.5	1.23315	1.23311	0.003
2.0	1.4427	1.4423	0.03
3.0	1.8204	1.8171	0.18
4.0	2.164	2.154	0.44
5.0	2.485	2.466	0.77
6.0	2.790	2.759	1.1
7.0	3.083	3.036	1.5
8.0	3.366	3.302	2.0
9.0	3.641	3.557	2.3
10.0	3.909	3.803	2.7

Example: A tubular heat exchanger is operated countercurrently with a temperature difference between the two liquids of 16.10°C at the inlet end and 6.34°C at the outlet end. What is the effective mean temperature difference?

Here the effective mean temperature difference is the logarithmic mean of the two temperature differences.

By Exact Formula:

$$a = 16.10, \quad b = 6.34$$
$$a - b = 9.76$$
$$\log (a-b) = 0.9894$$
$$\log a = 1.2068$$
$$\log b = 0.8021$$
$$\log a/b = 0.4047$$
$$\log (\log a/b) = \log 0.4047 = 0.6071$$
$$\log 2.303 = 0.3623$$
$$\log (2.303 \log a/b) = \underline{0.9694}$$

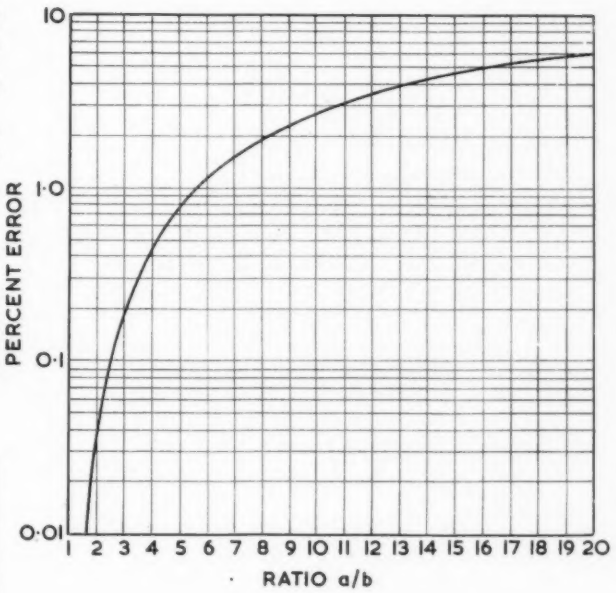

Fig. 1.

$$\log \frac{a-b}{2.303 \log a/b} = 0.0200$$

$$\frac{a-b}{2.303 \log a/b} = \text{Antilog } 0.0200 = 10.47°\text{C}$$

By Approximate Formula:

$a = 16.10$ $\qquad$ $\log a = 1.2068$

$b = 6.34$ $\qquad$ $\log b = 1.8021$

$\frac{a+b}{2} = 11.22$ $\qquad$ $\log \frac{a+b}{2} = \underline{1.0500}$

$$\log \left(a\,b\,\frac{a+b}{2} \right) = 3.0589$$

$$\log \left(a\,b\,\frac{a+b}{2} \right)^{\frac{1}{3}} = \frac{3.0589}{3} = 1.0196$$

$$\sqrt[3]{a\,b\,\frac{a+b}{2}} = \text{Antilog } 1.0196 = 10.46°\text{C}$$

The simplicity of the latter calculation is apparent. Where high accuracy is required, and where values of a/b are high, the exact percentage error in the approximate result may be determined from Table 1 or Fig. 1 and that result adjusted accordingly to give the exact solution.

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DESIGNING CONTROL ROOMS TO SUIT THE MEN IN THEM

The layout of the control room in a new chemical plant should be designed to suit the kind of man who will use it. Some of the specialized knowledge required is available in textbooks. A consultant, or, given time, a research unit may be able to supply the rest

by E. C. POULTON

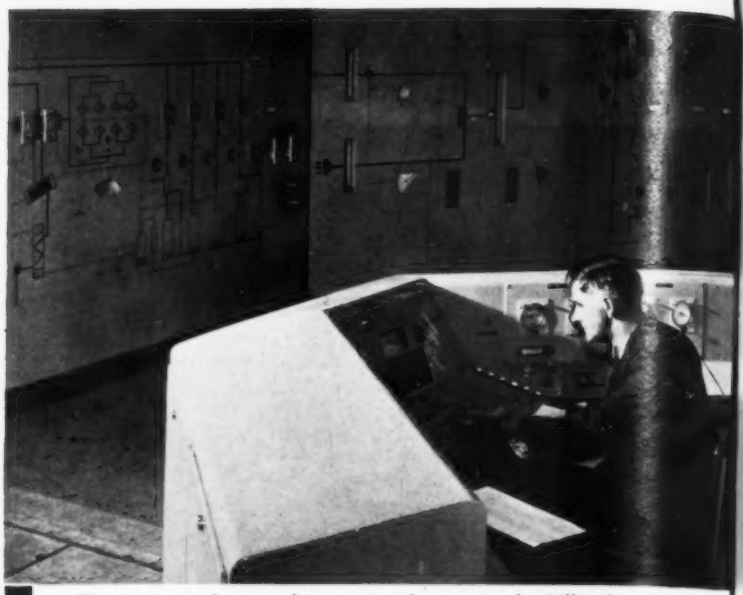

Fig. 1. A graphic panel in a control room at the Billingham Division of Imperial Chemical Industries Ltd.

What Kind of Man?

BEFORE deciding on the principles of design for a control room, the engineer ought to know the kind of person who will use it. It is sometimes assumed without question that a human controller or processman must be present in a control room, even when the plant will run automatically. If a processman is put in the control room of an automatic plant, PARKINSON'S law[5] predicts that he will soon find something to keep him busy. What needs to be assessed in these cases is whether or not the plant could run equally effectively if he were prevented from doing anything.

Emergencies should always be catered for by automatic devices where possible. Men are born with time lags built into them, and are liable to make mistakes. Delayed and possibly erroneous procedures cannot be tolerated in emergencies, owing to the high cost in capital loss and possibly also in human life. Thus the chance of an emergency does not in itself call for the presence of a processman in the control room.

If it can be demonstrated that a human controller or processman is not required in an automatic plant, this does not necessarily eliminate men from the control room. There may be a need for a man with a different function: a watchman whose sole duty is to call up the maintenance engineer as soon as anything has gone wrong, or the maintenance engineer himself while he is locating a fault.

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Design to Help the Man

The design of a control room should be suited to the needs of the kind of man who will use it. *Graphic panels* (Fig. 1) show how the readings on the different instruments are related. They may also show the relationship of the switches used in starting up the different parts of the plant to the instruments which record and control the reactions taking place in the parts. Thus they may be precisely what the maintenance engineer requires, as well as appealing to the plant designer, to the plant manager and to the casual visitor.

In providing graphic panels for a human controller or processman, the plant designer makes the implicit assumption that the processman has the background knowledge and ability to relate readings on the instruments to the conditions which are present in the parts of the plant to which the instruments relate. A careful examination often shows that even the better process operators do not do this. They simply operate their plant with reference to one or more key instruments, using rules which they have either picked up or been taught. They do not make use of most of the information which the graphic panel supplies.

Where this is the case, a *functional arrangement* of the instruments may be preferable (Fig. 2). Here the instruments which are important to the man are mounted on a central panel or console, with the less important instruments at the sides. The plant designer has to be able to determine at an early stage which will in fact be the key instruments from the operator's point of view, or the final arrangement may not be appropriate to the processman's method of operation.

Where controlling instruments may have to be *operated by hand*, the controls should be mounted directly beside or below the corresponding displays. This leaves no ambiguity as to which control corresponds to which instrument, and is thus likely to minimize errors during operation. If manual operation is often likely, the instruments should be mounted on a panel sloping at about 20° (Fig. 2), so that the man can rest his hand against the panel while making fine adjustments.

If the control room is to be used by a watchman whose principal job is to notify faults to the maintenance engineer, an alarm system should be incorporated. Auditory warnings are normally more effective than visual, since a visual warn-

ing will not be noticed until the man happens to look in the right direction. However, an auditory warning to alert the man can be combined advantageously with a visual warning to tell him which instrument requires attention. A bright flashing light close to the instrument may be preferable to a steady light, but either make the job of the man much easier than having to search several dozen instruments to see which is recording outside its specified limits of tolerance.

Whenever a man is expected to remain in a control room for hours on end, tolerable levels of temperature, lighting and noise should be maintained. Performance at many tasks tends to deteriorate when the *effective temperature*[1] rises above 78°F. Sedentary workers begin to complain when the effective temperature falls much below 60°F.

The *lighting* can be taken as adequate, provided the faces of the instruments reflect at least 20 footlamberts. This is a minimal value, the trebling of which may slightly improve visual efficiency. The man's eyes should be shielded from sources of glare such as bright lights and their reflections in highly-polished surfaces or in the glass covers of the instruments. Good contrast on the faces of the instruments requires the white faces to have a reflectance of at least 90 per cent, and the black lettering and indicators a reflectance of not more than 2 per cent. The recommended reflectance of the surrounds of the instruments, and of the panels and consoles in which the instruments are mounted, is from 20 to 40 per cent; they should not be black. Painting in pastel shades on the panels and walls of the control room may give it a pleasant colourful appearance. Very bright colours and high-gloss paints are not recommended.

Levels of noise of 90 decibels re 0.0002 dynes/cm^2 and above tend to produce deafness in those exposed for prolonged periods. Loud noises also interfere effectively with communication by voice, and may increase somewhat the number of incorrect decisions or accidents in the men exposed to them. Noise of high pitch is worse than noise of low pitch in this latter respect.

Sources of Information on Human Capabilities and Needs

Two general textbooks of engineering psychology are now available—CHAPANIS, GARNER and MORGAN[3] and MCCORMICK.[4] Both books have been written for readers without any specialized knowledge of applied psychology. Many of their recommendations appear to be nothing more than common sense, once the points have been made. The books do not supply ready-made solutions to the special problems of control rooms. They simply outline the principles which should govern design in its human aspects, and give some of the experimental evidence from which the principles were deduced. They also describe some of the techniques which can be used in applying these principles, and illustrate the kinds of practical improvements which can often be made. However, after reading one of the books the design engineer should be able to see more clearly in existing and proposed control rooms the good and bad points from the point of view of the men in them.

If the designer meets quite a new problem, there may be no relevant previous work to go on. In this case he may be able to persuade a *research unit* in applied psychology or ergonomics to work on it for him, especially if the problem is of general interest and is likely to become important and widespread in the future. But it is unlikely that sufficiently definite experimental results would be available for him to use in much under two years. Most of the benefits of the research would thus go to the designers of subsequent control rooms of a similar kind.

An alternative, if finances permit, is to seek the advice of one of the few *consultants* in this country who have worked on the human aspects of instrumentation. The consultant must be familiar with method study, and be experienced in redesigning work layouts. This should ensure that the needs of the man in the control room will be properly studied along with the other requirements of the instrument panel or console. These include ease of maintenance, low cost, adaptability for future changes, and economical use of space.

The designer would be well advised to obtain information or advice on human aspects whenever possible, even if in the end he does not use it. The final decision must be his, since he has to balance the human aspects against the other requirements. But at least he should be aware of the human aspects of his design, so that he can arrive at the best all-round compromise.

The Benefits of Engineering Psychology

A control room which is designed to meet the needs of the maintenance engineer should help him to learn quickly how the plant functions, and enable him to spot and locate a fault when it occurs, with the minimum of delay. This will reduce the time for which the plant is either running inefficiently or being shut down.

Where a human controller or processman is in charge of a control room, good design should enable him to minimize the number of shut-downs. Disasters such as that in the atomic power station at Windscale need never occur. In the chemical and petro-chemical industries the design may also enable the processmen to discover more quickly the exact method of operation which produces the highest percentage of the finished product. Until automatic methods of programming a plant for optimal running are available,[2] this will have to be left vary largely to the processmen.

ACKNOWLEDGMENTS

I am most grateful to JOHN B. KITCHIN, Personnel Director of Plastics Division of Imperial Chemical Industries Ltd., for his ideas, VICTOR H. BROWN, Instrument Manager of the Wilton Works of Imperial Chemical Industries Ltd., and C. J. P. BATESON, Personnel Director of the General Chemicals Division of Imperial Chemical Industries Ltd., very kindly arranged visits to modern chemical plants, and discussed some of the points made in this article.

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[1] BEDFORD, T. *Basic Principles of Ventilation and Heating*, 1948, page 45. London: Lewis.
[2] BOX, G. E. P. "Evolutionary Operation: a Method for increasing Industrial Productivity", *Appl. Statist.*, 1957, **6**, 81-101.
[3] CHAPANIS, A., GARNER, W. R., and MORGAN, C. T. *Applied Experimental Psychology*, 1949. New York: Wiley.
[4] MCCORMICK, E. J. *Human Engineering*, 1957, New York: McGraw-Hill.
[5] PARKINSON, C. N. *Parkinson's Law or the Pursuit of Progress*, 1958. London: Murray.

Fig. 2. A functional arrangement of miniature instruments on a console in the control room of a boiler plant at the Wilton works of Imperial Chemical Industries Ltd.

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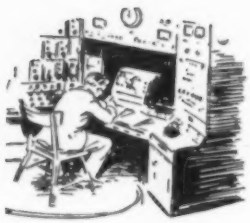
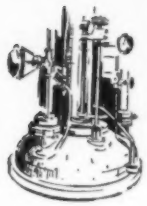


LETTERS TO THE EDITOR



Heat Pump in Multi-component Distillation

July 26, 1961

Gentlemen,

The June 1961 number carries an interesting article by D. C. FRESHWATER on "The Heat Pump in Multi-component Distillation". The paper discusses the possibility of reducing overall reflux requirements by increasing the reflux rate only in the pinch zones, and suggests the use of heat pumps to supply the intermediate reflux. The author points out correctly that by operating the heat pump only over the small temperature interval of the pinch, the efficiency of the operation is better than if the heat pump operates between overhead and reboiler.

The general excellence of the paper is marred by an error in the graphical presentation. In Fig. 2 the intermediate operating line is shown joining the two ends of the rectifying and stripping operating lines. For the simple binary case, which this figure illustrates, there must be two intermediate operating lines, and they intersect the diagonal at x_D and x_B, as do the terminal operating lines.

The attached Fig. 1 represents a column. For the binary case, the heat pump operates across the feed-plate and several adjacent plates. Assuming equimolal overflow, there will be four sections in the column, each with different liquid and vapour rates.

For the upper section the usual material balance around any tray and the top of the column is:

$$Y_{n+1} = \frac{L_1}{V_1}(x_n - x_D) + x_D$$

where the subscripts n and $n + 1$ refer to any tray in the section and to the tray below. For the second section, the liquid rate will be higher, since the heat pump is removing heat from the top tray of the second section. But no material is added or removed between the feed tray and the distillate; thus the sectional material balance for the second section is analogous to that for the top section:

$$Y_{p+1} = \frac{L_2}{V_2}(x_p - x_D) + x_D$$

Solving this equation for the intersection with the $y = x$ diagonal, we find:

$$y_I = x_D$$

That is, the operating lines for both sections meet the diagonal at x_D, but have different slopes.

Similarly, it can be shown that the operating lines for the two sections below the feed meet the diagonal at x_B. The intersections of both pairs of operating lines must occur on the so-called q-line, which for a saturated liquid feed is a vertical line through composition x_F. Fig. 2 is a rough plot of the $y - x$ diagram.

The general conclusions reached in the paper are not affected by this error, though the quantitative treatment (for example, the calculation of the heat saved in Table III) may be affected.

Yours very truly,

p.p. C. F. BRAUN & CO.,
HOWARD HIPKIN,
Research Engineer.

Alhambra,
California.

August 2, 1961

Dear Sir,

Thank you for your letter of July 31, enclosing the communication which you have received from MR. HIPKIN of C. F. Braun & Co.

MR. HIPKIN is quite correct in his criticism and there is, as he points out, an error in the graphical presentation in Fig. 2 in my paper. Since the heat pump introduces a new reflux ratio, then clearly there is a step change from one operating line to a new operating line and if the heat pump is applied across the feed plate there will, in fact, be two new operating lines as you have shown. This applies equally to multicomponent mixtures as to binaries, but in fact since multicomponent mixtures cannot be represented graphically for useful quantitative calculations, then this error has not carried over into the quantitative example where the calculations were performed analytically. This error, however, does not affect later stages of the paper, and in particular the quantitative treatment in the example quoted is unchanged, because in this case the heat pump was applied to a small section of the column above the feed plate, and, moreover, the calculations were carried out analytically and not graphically.

We are at present working out a number of cases for a multicomponent distillation using this principle with the aid of a digital computer and are obtaining some quite interesting results. I shall be pleased to discuss them with MR. HIPKIN.

D. C. FRESHWATER

Loughborough College of Technology.

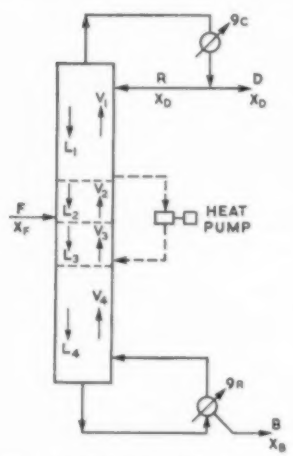


Fig. 1. Column with heat pump.

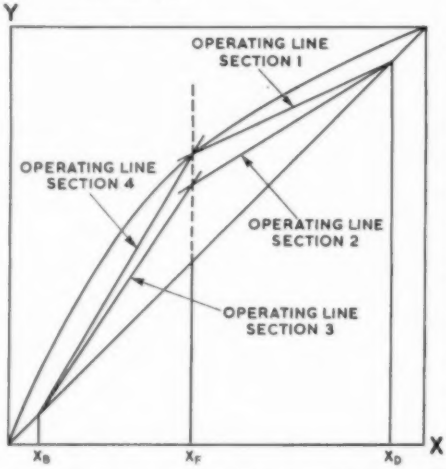


Fig. 2. McCABE-THIELE diagram for idealized binary system with heat pump.

Glass-fibre Wound Laminates

August 30, 1961

Dear Sir,

I have just received the September number of your journal. I found in it a résumé of my lecture in Birmingham.* Unfortunately, I have been badly reported, so that I appear to have made a statement which I have not made.

You say: "Vessels made by this method *cannot* be used at temperatures more than slightly above ambient temperatures. . . ." What I said was that the behaviour of glass-fibre laminates at elevated temperatures is different from that at ambient temperatures and that special precautions, physically and mathematically, must be taken if vessels (or pipes) are to be used at temperatures above 80° to 100°C. There are many pipes and vessels in use all over the world made by the fibre winding process which operates at about 100°C most successfully.

I would be most grateful if you could correct this error.

Yours very truly,

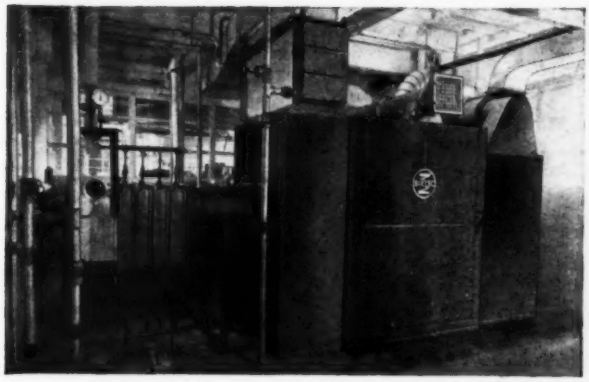
F. F. JARAY

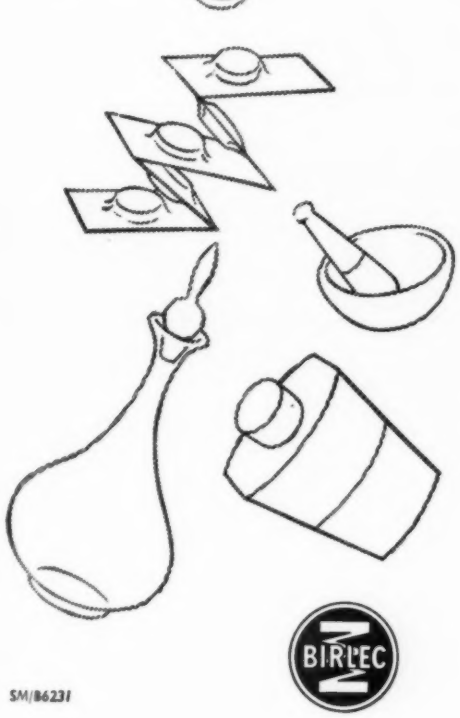
6 Sansome Place,
Worcester.

* *Brit. Chem. Eng.*, 1961, **6**, 620.

DRY HYGROSCOPICS

Model CO Dehumidifier installation at Reckitt & Sons Limited, Hull, for their Steradent process room.





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Abstracts

GROUP A — FLUID DYNAMICS

Some Hydrodynamic Aspects of Two-phase Flow and Boiling*
Part I: The Rise of Bubbles Through a Liquid

By measuring void fraction, relative velocity and agglomeration rate for the rise of air bubbles through various solutions, it has been possible to rationalize variations in experimental results already available in the two-phase flow literature. The results are found to lie between theoretical predictions for two ideal flow régimes, "bubbly" and "slug" flow (which assume no bubble agglomeration in the former case and agglomeration in the latter). The characteristics of these ideal flow régimes have been investigated experimentally as well as the process of transition between flow patterns.

The results are applicable to the prediction of two-phase flow pattern, voidage and pressure drop in systems in which the effects of wall shear stress are negligible. They are also of considerable importance for the understanding of the hydrodynamics of pool boiling.

Part II: Bubble Generation from a Submerged Surface

This paper describes experiments in which air was blown through the walls of a porous tube submerged in water. Three different flow patterns, "bubbly", "patchy" and "blanketed", were obtained, depending on the normal average air velocity from the tube surface. The results are used to explain hydrodynamic aspects of pool boiling. The bubbly flow pattern is shown to be analogous to nucleate boiling and the blanketed pattern to transition boiling. Treatment of the burn-out heat flux as a purely hydrodynamic phenomenon is justified.

G. B. Wallis. Paper presented at the 1961 International Heat Transfer Conference, held at the University of Colorado, U.S.A. Published by A.S.M.E., 29 West 39th Street, New York, 18, in *International Developments in Heat Transfer*, Part II, pp. 319-40.

Free Entrainment Behaviour in Sieve Trays

This is an analysis of the behaviour of entrained particles between sieve trays for the air-water system. The drop-size distribution was logarithmic. An equation was derived expressing entrainment as a function of distance above the froth. Results were within 28 per cent of experimental data. 22 refs.

S. I. Cheng and A. J. Teller, *A.I.Ch.E.J.*, 1961, **7** (2), 282-7.

Fluid Mixing in Shell and Tube Heat Exchangers

Studies of the transient behaviour of heat exchangers requiring a knowledge of the mixing of fluids. In this article the results of mixing obtained by temperature pulse-rate techniques are compared with predicted values obtained from simplified mixing theory. The mixing parameter $uL/4D$ appears to characterize the mixing in tube and shell exchangers. Mixing plays a dominant role in determining the dynamic response of heat exchangers. The pulse-testing technique is a satisfactory and rapid method of obtaining experimental data from which frequency response information may be computed. 6 refs., 4 charts, 2 tables.

G. C. Vincent *et al.*, *C.E.P.*, 1961, **57** (7), 48-52.

Compressibility of Real Binary Gas Mixtures

This is a detailed review of P-V-T-x properties of binary gas mixtures and their dependence on reduced temperature and pressure. For enginering calculations, a modified form of Kay's original method for estimating P-V-T-x properties is suggested.

J. S. Busch and L. N. Canjar, *A.I.Ch.E.J.*, 1961, **7** (2), 343-5.

Solids Mixing Studies in Gas Fluidized Beds. Part I: Comparison of Tapered and Non-tapered Beds

Tapering reduces the vertical mixing rate only in beds of dense materials over 2 ft high, and only at flow rates less than 30 per cent greater than the minimum fluidization velocity. A similar annular tapered bed does not show this effect. Most satisfactory tracing technique consisted in continuously sampling from various points. 17 refs.

K. S. Sutherland, *Trans. Inst. Ch. E.*, 1961, **39** (3), 188-94.

* Author's abstract.

Entrainment from a Submerged Combustion Evaporator

Entrainment from a submerged combustion evaporator system was studied with sodium ion as a tracer. By measuring the ratio of the sodium concentration in the pot to that in the condensate, the entrainment removal performance of the evaporator system was studied under various conditions. It was observed that the log of the concentration ratio decreases with an increase in the temperature of the gaseous products of combustion, as they emanate from the combustion chamber into the solution. This is attributed to the fact that a greater amount of fine ($<5\mu$) droplets of entrainment are formed in the evaporator as the temperature of the gases increases. 14 refs.

G. Rey, *A.I.Ch.E.J.*, 1961, **7** (2), 299-302.

Smoke-scattered Light Measurement of Turbulent Concentration Fluctuations

An optical method has been developed for measuring the concentration fluctuations at a point within systems undergoing turbulent mixing. Measurements of concentration fluctuations of a jet of smoke discharged into atmosphere agree well with comparable measurements of temperature fluctuations reported with the hot-wire anemometer. 15 refs.

R. E. Rosensweig *et al.*, *Chem. Eng. Sci.*, 1961, **XV** (1/2), 111-29.

Mixing of Highly Viscous Substances in a Multi-angle Mixer. Part 2: Experimental Results and Example of Application

The author describes the mixing process with reference to an analogy of unsteady heat exchange, and applies the process to the multi-angle mixer. He also discusses the application of such a mixer in synthetic fibre manufacturing plants.

P. Schaefer, *Chemie Ing. Tech.*, 1961, **33** (7), 493-7.

Two-phase Concurrent Flow in Packed Beds

Pressure drop and liquid saturation accompanying two-phase concurrent flow have been studied in a variety of packings with gas-liquid systems over a wide range of fluid properties. With non-foaming systems, two basic flow patterns were observed. 9 refs.

R. P. Larkins *et al.*, *A.I.Ch.E.J.*, 1961, **7** (2), 231-9.

Shape and Velocity of Single Air Bubbles Rising in Various Liquids

The shape and velocity of bubbles rising in various liquids were measured from photographs taken through a stroboscope. Liquids used were: NaCl/water solutions, glycerine/water solutions, ethanol/water solutions, acetic acid/water solutions, nitrobenzene, isoamyl alcohol, ethanol, toluene, ethyl acetate and water.

As bubble size increased, the shape changed from spherical to ellipsoidal, to mushroom-like. The bubble was spherical up to N_{Re} of $2M^{-0.23}$ (M = dimensionless parameter $g\mu^4/\rho\sigma^3$), and travelled in a rectilinear path. In the N_{Re} range $2M^{-0.23}$ to $16.5M^{-0.23}$ ellipsoidal bubbles were formed, and as the bubble size increased the shape became flatter. At $N_{Re} > 16.5M^{-0.23}$ the bubble was mushroom-shaped. All observed changes in shape were plotted vs N_{Re} as d/a vs $M^{-0.23} \times N_{Re}$, where d = equivalent spherical diameter, a = major axis of bubble. The results referred to above apply to air bubbles in all solutions, except surface-active agent solutions in which larger bubbles remain spherical. For spherical and ellipsoidal bubbles, the surface tension, σ, and viscosity, μ, were important factors in determining the rate of rise. Mushroom-shaped bubbles rose independently of liquid properties. The drag coefficient C_D was also expressed in terms of N_{Re} and M as follows:

$$C_D = 2.6, \text{ for } N_{Re} > 16.5M^{-0.23}$$

$$C_D = 1.25(N_{Re} \times M^{0.23})^{.26}, \text{ for } 16.5M^{-0.23} > N_{Re} > 6M^{-0.23}$$

$$C_D = 0.076(N_{Re} \times M^{0.23})^{1.82}, \text{ for } 6M^{-0.23} > N_{Re}$$

The equations agreed approximately with data reported by previous investigators. 17 refs.

T. Takadi and S. Maeda, *Chem. Eng., Japan*, 1961, **25** (4), 254-64.

Brit. Chem. Eng. Abstracts: **FOLIO No. 32**

BCE 514 for further information

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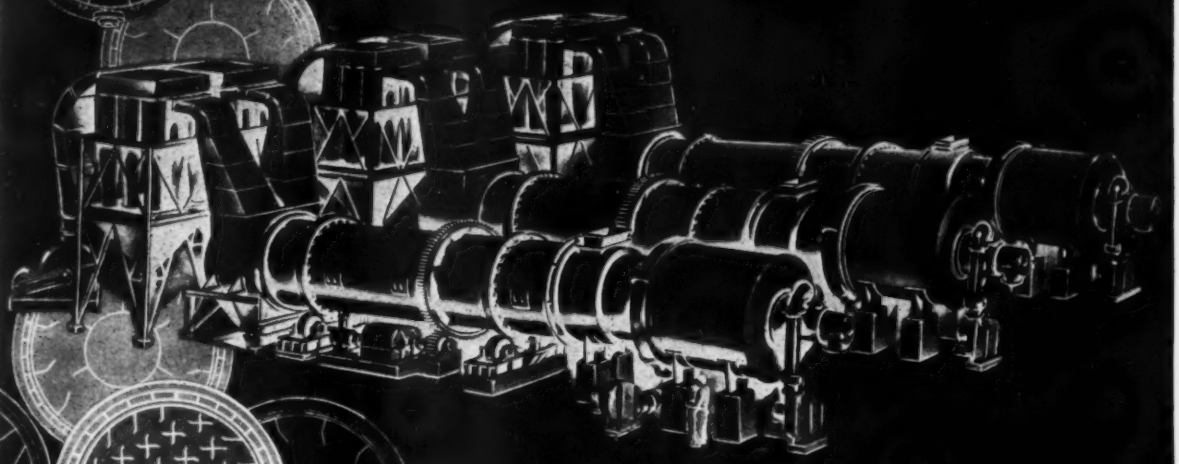
ROTARY DRYERS

FOR IRON ORE PLANT



Head Wrightson is supplying six rotary dryers to Richard Thomas & Baldwins Limited, measuring 10 ft. in diameter, 45 ft. long, for installation at their Redbourn and Spencer Works. These dryers will be capable of handling a weekly output of 42,700 tons of ore processing from 0 to 2½". It is believed that these machines will be the most highly instrumented of their kind in this country.

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Abstracts

GROUP B — HEAT TRANSFER

Prediction of Emissivity of Hydrocarbon Flames

The emissivity of a luminous flame has been calculated from the observed optical properties of soot (the real refractive index, n, and the absorption index, k), using Mie's theory for the case where the soot particles are much smaller than the important wavelengths. The resulting formula shows that the differential luminous emissivity is proportional to the mass concentration of the soot, but effectively independent of the particle size.

M. W. Thring *et al.* Paper presented at the 1961 International Heat Transfer Conference, held at the University of Colorado, U.S.A. Published by A.S.M.E., 29 West 39th Street, New York, 18, in *International Developments in Heat Transfer*, Part IV, pp. 796-803.

Thermal Conductivity of Heterogeneous Materials

The available methods for predicting conductivities of heterogeneous materials are evaluated. Simple expressions are derived for dispersions, packed beds and for materials in which both phases are continuous. These expressions agree very well with experimental results. 46 refs., 6 charts.

R. L. Gorring and S. W. Churchill, *C.E.P.*, 1961, **57** (7), 53-9.

Thermal Decomposition of a Solid

A mathematical analysis is derived for the heat transfer of non-catalytic thermal decomposition, in single spheres and packed beds, allowing for the temperature gradient within the solid. The equations are based on the assumption that (a) the specific heat of solid is small compared to the heat of decomposition; (b) the heat transferred to the surface is all used as decomposition heat; (c) the difference between the decomposition temperature and the surrounding temperature is moderate.

The mathematical solutions obtained for single spheres and packed beds agree fairly well with experimental results obtained with $CaCO^3$. 11 refs.

S. Sugiyama *et al.*, *Chem. Eng., Japan*, 1961, **25** (4), 265-73.

High-velocity Combustion Applied to Chemical Processing

The characteristics and requirements of high-velocity combustion are discussed and illustrated with an example of a high-velocity gas burner and a high-velocity residual oil burner. 2 diag.

Anon., *C.E.P.*, 1961, **57** (7), 94.

Dynamic Behaviour of Forced-flow Evaporator Systems

The dynamic control behaviour of forced-flow evaporator systems is very important in the control of once-through forced-circulation boilers, and also in drum-type boilers with steaming economizers. It plays a major part in determining the nature of the feed control system, and to some extent it also affects the properties of the boiler as a whole.

A combined graphical and mathematical method is here developed by which the transfer characteristics can be determined from the design data of the steam generator. This also provides a clear picture of the complicated processes taking place in such a heating system under transient conditions.

P. Profos, *Sulzer Tech. Rev.*, 1960, **42** (4), 5-12.

Fischer-Tropsch Synthesis with Tubular Reactor of 18.1-l. Catalyst Bed. 1: Reactor with Constant Temperature Wall

A calculating procedure previously developed from experimental data obtained with a reactor of 2-l. catalyst bed was used to predict the temperature profile of a reactor having a catalyst bed of 18.1 l. The predicted temperature profile expresses the tendencies observed in the actual synthesis with the latter reactor, though complete agreement has not yet been obtained because of a lower output than was expected. 18 refs., 1 diag., 3 charts.

M. Kuraishi *et al*, *Bull. Chem. Soc., Japan*, 1961, **34** (6), 780-5.

Boiling Heat Transfer

In this article a generalized equation for boiling heat transfer is derived which can be modified for application to the nucleate and film zones. The equation agrees well with experimental results reported. 10 refs., 6 charts.

H. K. K. Muthoo, *Chem. Proc. Eng.*, 1961, **42** (8), 348-50.

Binder-Schmidt Method for Non-steady-heat-source Problems

In heat transmission numerous solutions are known for steady-heat-source problems. With non-steady-heat-source problems the temperature variation with time is determined, but there is no practical solution for such cases. In this paper the author extends the Binder-Schmidt method to non-steady-heat-source problems. 12 refs., 4 charts, 1 table.

G. Luck, *Chemie Ing. Tech.*, 1961, **33** (8), 547-50.

* Author's summary.

GROUP D — PHYSICAL SEPARATORS

Study on Electro-precipitator Performance in Relation to Particle Size Distribution, Level of Collection Efficiency and Power Input

Three major aspects of precipitator performance are investigated: size distribution, level of collection efficiency and power input. Large-scale test results yield fractional efficiency or migration velocity curves which are at variance with theory. An average curve from practical large-scale tests is used for calculating the effect of particle size distribution of efficiency and the effect of high-efficiency levels on migration velocity. Calculated results are compared with full-scale plant results. The theoretical basis for the influence of power input is given and compared with test results.

Both in theory and in practice, a larger amount of fine particles markedly reduces the average migration velocity. A similar marked effect predicted for increase in the level of efficiency has not been found in practice. Relatively closest agreement between migration velocity and current input is found, next comes h.t. power input, but agreement has been found between migration velocity and h.t. voltage.

D. O. Heinrich, *Trans. Inst. Ch. E.*, 1961, **39** (2), 145-54.

The Present State of Knowledge in Salt Flotation

The possibilities for explaining the selective effect of collecting reagents are summarized on the basis of the present state of knowledge. After citing the most important publications of recent years, the flotation theories for ion exchange, bond formation, structure similarity or hydration are discussed, for the main part with our own experiments. On the basis of this, it is by no means possible to explain the phenomena of selective flotation theoretically in an unambiguous manner; the purpose of the present paper is to stimulate further discussion. The object is to comprehend the molecular reaction mechanism in order then to reach certain flotation results from knowledge and not from accidents of the experiments, and thus to refine the process which is already being employed technically on a very large scale.

A. Singewald, *Chemie Ing. Tech.*, 1961, **33**, 376.

How Dust Filter Selection Depends on Electrostatics

Research on the selection of fabric filters for dust collection shows that electrostatic properties of both the dust and the collecting fabric are critical in determining filtration performance. This paper incorporates these facts into classical filtration theory to provide a better solution to dust filtration problems.

E. R. Frederick, *Chem. Eng.*, 1961, **68** (13), 107-14.

Filter Performance Under Field Conditions

The evaluation of filter performance on the basis of constant rate or constant pressure is suitable for collecting laboratory data for filter design purposes. Under actual plant conditions of variable rates and pressures, the method presented in this article is suggested. It is based on volume-time and pressure-time data. 3 refs., 4 charts, 4 tables.

C. A. Jahreis, *C.E.P.*, 1961, **57** (7), 60-2.

Top Feed Filtration and Drying

The authors discuss the operation, theory and design of top-feed filters and driers with examples of their applications in sugar and metal industries. Their use primarily depends on the size distribution of feed solids and the rate of cake formation. The minimum size limit is 30 per cent −200 mesh and very small amounts of −5 micron. At least 1 in. of cake should form in 10 sec. Filter design should produce an even cake distribution. 4 refs., 6 charts.

R. C. Emmett, Jr., and D. A. Dahlstrom, *C.E.P.*, 1961, **57** (7), 63-7.

Crystallization Review

A review of this unit operation which includes recent fundamental investigations into crystal structure. 86 refs.

A. W. Bamforth, *Chem. Proc. Eng.*, 1961, **42** (8), 353-6.

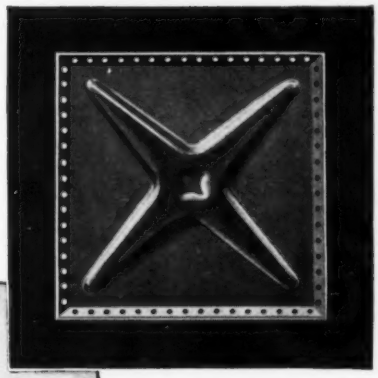
The Effects of pH on the Flocculation of Quartz Aqueous Suspensions*

The effects of pH on the flocculation of quartz aqueous suspensions containing Ba^{2+}, Fe^{3+} or Cu^{2+}, respectively, were investigated by means of electrokinetic measurements. The violent flocculation takes place in the characteristic range of pH with respective cation involved. The calculation of the potential energy between approaching quartz particles indicates that the violent flocculation is readily explained, not by the decrease of electrical repulsion, but by the consideration of an attractive force other than van der Waals' attraction. 9 refs., 5 charts.

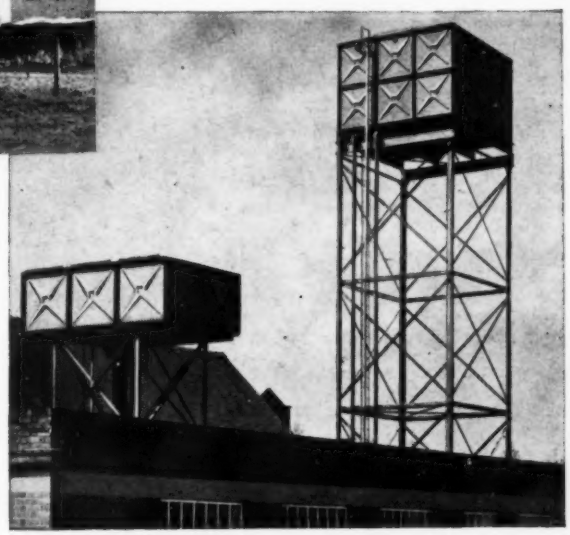
T. Ohyama *et al.*, *Bull. Chem. Soc., Japan*, 1961, **34** (6), 790-4.

Brit. Chem. Eng. Abstracts: **FOLIO No. 33**

Braithwaite



Pressed Steel Storage Tanks



Simple to erect with all tools provided, these sectional tanks ensure reliable storage for water, heavy fuel oils and other liquids. Available in capacities from 200 gallons upwards. (*Above*) A covered water tank for from 19,000 gallons, 20′ × 20′ × 8′ deep, supplied to a housing estate. (*Right*) The two other tanks illustrated (6,700 gallons and 2,200 gallons) serve the boiler house at a modern hospital.

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Abstracts

GROUP E — PROCESSING

Development of Phosphating Techniques

The author describes recent progress in the phosphating process for corrosion protection. Aspects considered are acceleration of the chemical reaction to produce phosphate layers having the desirable characteristics of hardness, fineness, binding power etc. He also points to the advantages of crystalline phosphating over amorphous phosphating.

R. LAGARDE, *Corr. et Anticorr.*, 1961, **9** (6), 203-5.

Liquid Polysulphide Polymer Manufacture

This article describes a typical polymerization process for manufacture of liq polysulphide polymer used as solid propellant binder. The reaction is essentially between sodium polysulphide and dichloroethylformal with small amounts of trichloropropane, $Mg(OH)_2$, and sodium alkyl naphthalene sulphonate.

E. R. BERTOZZI and W. O. HELMER, C.E.P., 1961, **57** (6), 96.

Reducing Gases by Partial Oxidation of Hydrocarbons

Recent trends towards the direct reduction of ores led to the versatile Shell gasification process which produces a variety of H_2/CO mixtures from hydrocarbon feedstocks ranging from natural gas to heavy fuel oils and asphalt. O_2 may be used from 99 per cent to 21 per cent purity. $CO + H_2$ content may be 96 per cent or less. The ratio $CO:H_2$ may vary between 1.0 and 2.0 with Bunker C fuel as feed. Soot content of gas may be reduced to 1 ppm by scrubbing. Exit temperatures can vary from 95°F (with low C content) to 2700°F (with high C content). Gas pressures may be 1-600 psig.

The process therefore can economically produce the quality requirements for a variety of ore reducing processes, and it is expected to promote new commercial direct ore reduction processes. 13 refs., 4 flow diag., 2 charts, 4 tables.

S. C. SINGER, Jr., and L. W. TER HAAR, *C.E.P.*, 1961, **57** (7), 68-74.

Which Acetylene Feed is Best?

The overall cost of producing acetylene has been compared for methane, ethane and propane feedstocks. Actual yields of acetylene are compared with theoretical yields, and the heat and oxygen requirements are also considered.

D. C. LOCKWOOD, *Pet. Ref.*, 1960, **39** (11), 223-6.

Polyolefin Processes Today

This is an extensive review of the literature and patents referring to polyolefin plastics. Process characteristics which control polyolefin processes are discussed, with special reference to the action of the catalyst.

M. SITTIG, *Pet. Ref.*, 1960, **39** (11), 162-222.

New Process for Pure Iso-amylenes

A new sulphuric acid process is described which produces approximately 99 per cent isoamylenes from the C_5 fraction of gasoline. 2-methyl-2-butene and 2-methyl-1-butene are separated from the C_5 fraction in a ratio of 9:1. A flow diagram is provided and details of a pilot plant are included.

R. L. FOSTER *et al.*, *Pet. Ref.*, 1960, **39** (11), 229-32.

Acrylonitrile

In view of the bright prospects for acrylonitrile, the first section of this article reviews the manufacturing processes based on (a) acetylene; (b) propylene; (c) ethylene; (d) lactonitrile. The second section discusses the chemistry of acrylonitrile, and the third its outlets in acrylic fibres, rubber, plastics, surface coatings, polyelectrolyte flocculating agents, cyanoethylation of cellulose, carbohydrates and proteins, organic synthesis and fumigants. 57 refs.

D. W. MCDONALD *et al.*, *H.P. & Pet. Ref.*, 1961, **40** (7), 145-54.

A Magnetic Method of Water Treatment

A magnetic device for the production of reagentless water for boilers and steam turbines used in the fats industry is described. The carbonate and permanent hardness salts, dissolved in the water for one or two days, lose their ability to form deposits after the water has been passed through a magnetic field. Instead of scale, an amorphous sludge is formed in the heat-exchange equipment; this sludge is easily removed by blow-down devices.

A. S. GODUN, *Masloboyno-Zhir. Prom. U.S.S.R.*, 1959, **25** (9), 41-3. Translation No. 61-15920, available in microfilm or photocopy, price $1.80, from: Photoduplication Service, Publication Board Project, Library of Congress, Washington, 25, D.C., U.S.A., or from SLA Translations Center, The John Crerar Library, 86 East Randolph Street, Chicago, 1, Illinois, U.S.A.

New Gas Treating Process

The article describes the Stretford process which reduces the H_2S content of gas to below 0.1 ppm. It is a continuous absorption process operated at ambient temperature and moderate pressure. The sulphur produced is free from arsenic and iron oxide and can be produced with 99.9 per cent purity.

This process is expected to have a variety of profitable applications.

ANON., *Pet. Times*, 1961, **65**, 137.

Some Problems in Planning and Operation of Pitch Coke Plants

A number of problems which arose at a particular pitch coke plant are discussed. Items covered are pitch coke ovens, coke screening, gas condensation, and instrumentation.

I. P. DOBROVOLSKII *et al.*, *Coke & Chem., U.S.S.R.*, 1961 (1), 30-3.

Determination of the Gas Content of the Air on Coke Ovens

This simple method, based on colorimetric analysis of a solution of the tar, which is always present in crude coke oven gas, was developed to estimate the gas content of the air on working platforms. Air is drawn through a filter packed with cotton wool. The tar deposited on the filter is dissolved in benzole and its content determined colorimetrically.

Standardization and calibration are necessary. The test is sufficiently accurate for all practical purposes.

P. I. TURCHENKO and A. V. OSTAPCHENKO, *Coke & Chem., U.S.S.R.*, 1961 (2), 29-30.

Recovery of Benzole Hydrocarbons from Acid Tar and Extraction of the Residue

Benzole can be stripped from acid tar by first mixing the tar with water. The tar is dissolved by diluting with water at 50-60°C. The benzole is then stripped with live steam at 150°C and 4 atm.

M. M. SORTAN *et al.*, *Coke & Chem., U.S.S.R.*, 1961 (3) 46-7.

A Comparative Investigation of the Methods of Heating Coal using Gas as the Heat-transfer Medium

Experimental results are presented of a comparison between heating coal by fluidization, dropping attachment and under eddy conditions. The apparatus was a glass column 60 mm dia and 1200 mm long, and coal of two sizes was used, below 1 mm and 1-3 mm. 7 refs., 3 figs., 2 charts, 1 table.

A. V. CHECKETKIN, *Coke & Chem., U.S.S.R.*, 1961 (2), 16-22.

Cleaning Waste Gases from Open-hearth Steel Processes

A major problem in the steel industry is cleaning the waste gases from open-hearth furnaces. This article reviews present processes and future developments for cleaning fumes; bag filters, slag wool filters, pebble bed filters, venturi scrubbers, electrostatic precipitation, coagulation of fume particles by sonic energy, thermal diffusion, magnetic fields. 7 refs., 5 diags.

W. STRAUSS, *Min. & Chem. Eng. Rev. (Aust.)* 1961, **53** (9), 50-5.

The Production of Slag Wool

Reference is made to the method employed at the Sukremlskoje iron foundries to produce slag wool. Slag now provides a profitable by-product in the form of slag wool which is used for insulation purposes. Molten slag emerging from a nozzle meets a jet of air which transforms the slag into fine fibres.

Experiments using a steam jet did not give satisfactory results. The slag outlet of the cupola furnace was modified to supply slag in a continuous stream. The slag entrained in the form of droplets by the air jet passes through a funnel into the collecting chamber. Oil is added to the air jet as this improves the adhesive properties of the fibres formed from the droplets.

Although this process results in an increase of 0.35 per cent in fuel consumption, the cost of crushing and remelting the solid slag is eliminated. For an initially small capital outlay an annual saving of 800,000 roubles could be achieved.

A. S. SEROW, "Schlackenwatte in Graugiessereien" in *Litejnoje Proiswodstwo (U.S.S.R.)*, No. 1, 1960: German translation in *Die Presse der Sowjetunion (D.D.R.)*, No. 137, 1960.

Removing CO from NH_3 Synthesis Gas

The paper shows how CO in NH_3 synthesis gas streams at higher pressures may be selectively converted to CO_2 with limited O_2 additions. Pt catalyst promotes the oxidation. 3 refs., 2 charts, 3 tables.

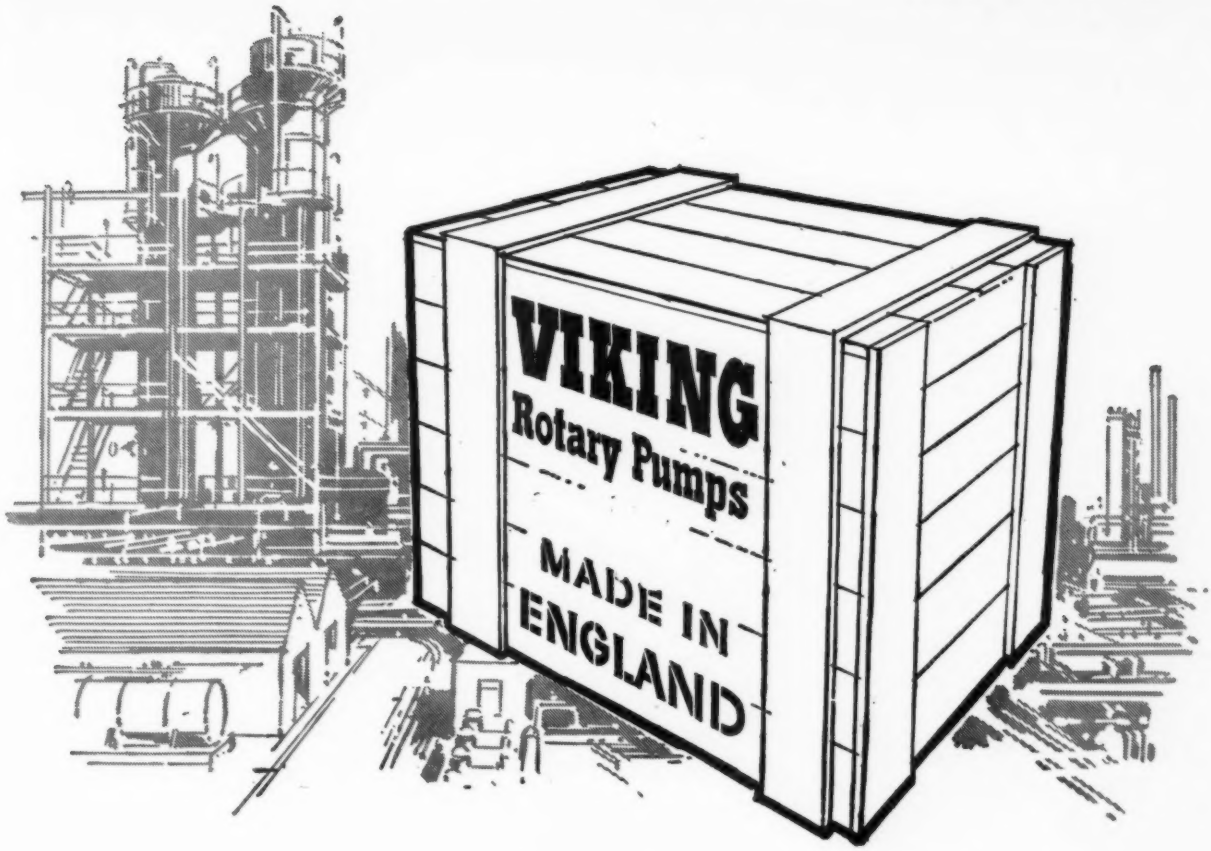
H. C. ANDERSEN and W. J. GREEN, *Ing. Eng. Chem.*, 1961, **53** (8), 645-6.

Thermal and Catalytic Decomposition of Hydrocarbons

This unit process review covers the period April 1960, to February 1961. Most significant development has been the commercialization of hydrodealkylation of alkyl aromatics to produce benzene and naphthalene. 88 refs.

A. J. DE ROSSET and C. V. BERGER, *Ind Eng. Chem.*, 1961, **53** (8), 680-2.

Brit. Chem. Eng. Abstracts: **FOLIO No. 34**



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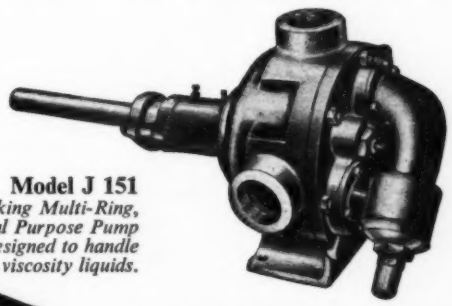

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Abstracts

GROUP F—PROCESS CONTROL

Industrial Flame-failure Systems

This article discusses the recent trends in equipment used for sensing the presence of flame in combustion chambers and for supplying fuel to the burners.

P. R. Prior, *Instrument Pract.*, 1961, **15**, (6), 726-30.

Automatic Controls in Oil Burner Installations

The author briefly compares the different types of oil burner and discusses burner modulation, flue draught control, flame-failure protection and automatic starting. A set of tables is included for selecting an oil burning installation and the items required for a specific control system.

F. B. Rider, *J. Inst. Heat. & Vent. Eng.*, 1961, **29**, 80-94.

Automation of the Air Supply to a Coke Battery Heating System

The methods used for regulating the air for burning gas in the oven heating systems and keeping constant the excess-air ratio or the vacuum under the regenerator. Three new methods which were investigated at an iron and steel works are described in this paper: (1) a system of regulating the vacuum in the regenerators and correcting according to the temperature in the tunnel; (2) a system of regulating the draught in the horizontal flue and correcting according to the gas and air parameters; (3) a system of regulating the cross-section of the air intake to the gas-air valves with thermobimetallic regulators.

F. A. Mustafin *et al.*, *Coke and Chem., U.S.S.R.*, 1961 (1), 25-30.

Optimization of Process Performance

This paper discusses a number of programmes for carrying out a search of the possible settings of the process input variables, so as to locate the possible values of a chosen objective function. The emphasis at the beginning of the search is on speed in moving towards the optimum, and at the end on accuracy. 12 refs.

L. Lapidus *et al.*, *A.I.Ch.E.J.*, 1961, **7** (2), 288-94.

Controlled Cycling Improves Various Processes

In controlled cycling, the time for each part of the cycle, or amount of material moved in each part of the cycle, or both, is controlled by automatic equipment. This short article reviews the applications of controlled cycling to distillation, liquid-liquid extraction and particle size separation. 6 refs.

M. R. Cannon, *Ind. Eng. Chem.*, 1961, **53** (8), 629.

Gas Chromatography and its Possible Application to Process Control

A gas chromatograph installed in a sulphur plant of capacity 30 tons/day repaid its cost in less than one year because it resulted in a 3 per cent increase in yield.

The sulphur was extracted from natural H_2S by part oxidation to SO_2, which reacts with the remaining H_2S to give sulphur and water. The feed varied so much in volume and concentration that the yield was only 85 per cent, in spite of frequent analyses of the exhaust gas. It was realized that the yield would increase by strict control of the H_2S to SO_2 ratio in the gas leaving the cooler, this ratio being used to regulate the air intake. The process was made automatic by installing a chromatograph which determined the content of H_2S and SO_2 in the exhaust gas. The two signals were sent to a computer which controlled the air supply.

Anon., *Teknisk Ukeblad*, 1961, **24**, 547-53.

Measuring Boiling Points Continuously

The paper discusses the use of on-stream analysers designed to measure b. pts. Six of them were installed on a distillation unit to monitor its performance. The analysers were tested by replacing the normal streams with standard samples. Their performance was most satisfactory and, with only one exception, they gave more consistent results than the lab. distillation apparatus. 1 chart, 5 flow diags., 10 tables.

M. W. Luther and C. K. Donnell, *H.P. & Pet. Ref.*, 1961, **40** (7), 169-74.

Automation Today

This is a discussion of analogue and digital computers which could assist in deciding which will best handle a particular process control problem. Three charts based on U.S. costs are included. 16 refs.

T. J. Williams and V. A. Lauher, *H.P. & Pet. Ref.*, 1961, **40** (7), 175-8.

GROUP H — DESIGN

Calculation of Flue Gas Recirculation and Heat Transfer in Heaters using High-velocity Gas Burners

To improve gas-fired heater performance, higher pressures are applied to the combustion gas in order to increase gas velocities and heat transfer. This is often done with a high-velocity air blast burner in which high-pressure air induces low-pressure gas through the combustion chamber and nozzle.

This paper deals with the effect which recirculation in such burners has on heat transfer, and illustrates the methods which may be used in design calculations for such burners. The calculations are complex, but may be solved by trial and error, using computer techniques.

W. E. Francis and H. E. Roughton. Paper presented at the 1961 International Heat Transfer Conference, held at the University of Colorado, U.S.A. Published by A.S.M.E., 29 West 39th Street, New York, 18, in *International Developments in Heat Transfer*, Part I, pp. 151-8.

Heat-transfer Coefficients in Town-gas Heated Equipment

145 experimental values of overall coefficients of heat transfer have been collected during recent work on gas-heated equipment for which precise calculations of heat transfer cannot be made. These were central heating boilers, water sterilizers, steam boilers, air heaters, water stills, fish friers, café boilers, wash boilers, etc. The results should provide a useful guide in designing new equipment.

E. A. K. Patrick and N. G. Patel. Paper presented at the 1961 International Heat Transfer Conference, held at the University of Colorado, U.S.A. Published by A.S.M.E., 29 West 39th Street, New York, 18, in *International Developments in Heat Transfer*, Part I, pp. 135-41.

The Design of a Natural-draught Cooling Tower

The paper discusses an asbestos-cement packing that is competitive with conventional timber packings. This asbestos-cement packing results in a smaller and simpler tower, and a number of such towers are now being built at British power stations.

R. F. Rish. Paper presented at the 1961 International Heat Transfer Conference, held at the University of Colorado, U.S.A. Published by A.S.M.E., 29 West 39th Street, New York, 18, in *International Developments in Heat Transfer*, Part V, pp. 951-8.

Suggested Design Methods for the Application of Spray Evaporation to a Steam-cooled H.W.M. Reactor

These suggestions are presented with reference to prediction of pressure drop; flow instability; maximum allowable heat flux; prediction of heat-transfer rates; deposition of materials on heated surfaces; liquid hold-up and coolant density.

J. G. Collier, U.K.A.E.A., Harwell, Report No. A.E.R.E. M-707, 10 pp, 3s. net.

Effect of Tube Spacing and Arrangement upon the Fouling Characteristics of Banks of Tubes

The utilization factor of a steam plant depends to a large extent on the time during which the boiler can be operated without overhauling. This time is partly affected by the susceptibility of the boiler heating surfaces to fouling. The arrangement of the tubes in the banks plays an important part, and a knowledge of the influence exercised by tube arrangement is essential if optimum design of heating surfaces is to be achieved.

This article describes the results of model tests which were conducted in the Sulzer thermal laboratory to obtain data relating to the effect of pipe geometry on the fouling of tube banks.

P. Profos and H. N. Sharan, *Sulzer Tech. Rev.*, 1960, **42** (4), 31-43.

Sizing of Vapour Relieving Systems

The author outlines the factors which must be considered in sizing vapour relieving systems, and the codes applicable to pressure vessels in the U.S.A. He discusses the characteristics of various types of relief valve and derives equations for calculating the vapour relieving capacity of these valves, of the headers and lateral lines.

J. Conison, *Petroleum, Lond.*, 1961, **24**, 57.

Calculate Pressure Drop for Flowing Gases

Tables are presented from which may be calculated turbulent-flow pressure drops for methane, oxygen, air, nitrogen and other gases. These tables are limited to pressure drops of 10 per cent of the upstream pressure or less. Results are comparable to those obtained by using the Fanning friction factor for clean steel pipe.

F. Lipinski, *Chem. Eng.*, 1961, **68** (14), 164.

Design of Knock-out Drums

Knock-out drums are vessels designed to separate liquids from vapours, i.e., separate oil and water from air or gas. A vertical drum is suggested for light mist entrainment (less than 1 gpm of liquid) and a horizontal drum for heavy vapour-liquid separations.

E. R. Niemeyer, *Pet. Ref.*, 1961, **40** (6), 155-6.

Brit. Chem. Eng. Abstracts: **FOLIO No. 35**

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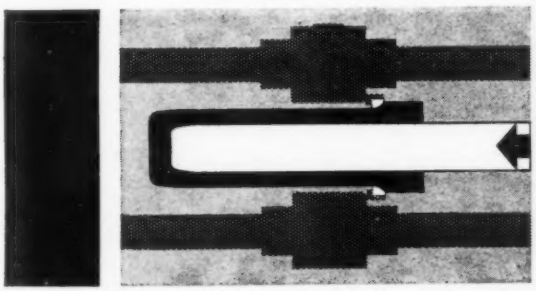

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Abstracts

GROUP H — DESIGN (cont.)

Kinetic Plots Aid Catalyst Operations

A new method is described for plotting performance data for catalytic reactors. This should help the designer to plan for improved operation and the plant operator to achieve it. The method is illustrated with the example SO_2 conversion to SO_3.

D. B. BURKHARDT, *Chem. Eng.*, 1961, **68** (13), 115-16.

Venturi Feeder for Dry Bulk Materials

The article describes how a venturi feeder can be designed for introducing light powdered material into an air stream. This is a low-cost, low-maintenance device which can be easily fabricated by a sheet-metal shop.

E J. GIBBONS, *Chem. Eng.*, 1961, **68** (14), 158.

Graphs Cut Exchanger Design Time

A graphical method is described for determining the minimum size of heat exchanger required, provided the maximum allowable pressure drop on the shell and tube side, and the heat duty are known. The method applies to gases and liquids under viscous or turbulent conditions when there is no phase change.

J. STARCZEWSKI, *Pet. Ref.*, 1961, **40** (6), 165.

Characteristics of Pneumatic Atomization

This study of pneumatic atomization has led to correlations which will determine the conditions of air and liquid streams necessary to produce sprays having mean diameters 5-30μ at liquid rates from $\frac{1}{2}$-5 gal/hr. The correlations are specific to two types of nozzle design. Several observations are reported. 16 refs.

J. GRETZINGER and W. R. MARSHALL, JR., *A.I.Ch.E.J.*, 1961, **7** (2), 212-18.

Utilization of Fission Fragment Energy for Fixation of Nitrogen

This is a review of process designs for the production of fixed nitrogen by the direct use of fission fragment recoil energy. It appears that this method offers no clear-cut advantages over conventional processes, even in a nuclear economy. 29 refs.

M. STEINBERG *et al.*, *A.I.Ch.E.J.*, 1961, **7** (2), 329-35.

Designing Thermosyphon Reboilers

The article describes a step-by-step procedure for designing thermosyphon reboilers, which requires prediction of liquid circulation rates, heat transfer film coefficients and overall temperature differences. Correlations for estimating these parameters are given. 9 refs. 3 charts.

G. H. HUGHMARK, *C.E.P.*, 1961, **57** (7), 43-7.

High-pressure Hydrogen—A Lab. Utility

The article provides details of a central H_2 compression system which has resulted in a lower cost per unit volume of H_2 supplied to a pilot plant, by receiving H_2 in a tube trailer instead of in cylinders. The economic aspects are based on current U.S. prices.

W. H. CAMPBELL, *Ind. Eng. Chem.*, 1961, **53** (7), 38A-41A.

How Big a Plant?

In determining the capacity of a plant, it is worth knowing that the costs of overdesign (primarily wasted capacity) are generally unequal to the cost of underdesign (lost potential profit).

The authors use algebraic models to develop equations from which the optimum capacity may be determined.

S. W. HESS and J. B. WEAVER, *Ind. Eng. Chem.*, 1961, **53** (7), 43A-44A.

Failure of a Thick-walled Pressure Vessel

A brief case history of the failure of a presumably well-designed high-pressure reactor 9 in i.d. This failure was caused by stress corrosion of the notch-sensitive steel, which resulted in brittleness.

E. SAIBEL, *Ind. Eng. Chem.*, 1961, **53** (7), 48A-49A.

Design of Filtration Equipment

This article is aimed at assisting a designer to select and effectively design a filtration system.

W. C. SMITH and R. C. GIESSE, *Ind. Eng. Chem.*, 1961, **53** (7), 538-45.

Dynamics of Liquid-solid Fluidization

For design of fluidized beds, a simple and direct method is given for determining void fraction and minimum fluidizing velocity. A condensed version of the original paper appears here.

S. H. BRANSOM and S. PENDSE, *Ind. Eng. Chem.*, 1961, **53** (7), 575-6.

GROUP G — MISCELLANEOUS

Boosting Pipeline Flow Efficiency

Tests made to assess the effect of sand-blasting on pipeline efficiency showed that sandblasting gives a cleaner pipe than either pigging or in-place coating. The efficiency of sandblasted pipes is within 3 per cent of the theoretical maximum.

A. W. MCANNEY and L. C. SULLIVAN, *Oil Gas J.*, 1961, **59** (11), 141-8.

Reaction Rates in Non-isothermal Catalysts

Reaction rates in non-isothermal catalyst pellets have been calculated by solving the non-linear differential mass and energy balances on an analogue computer. Calculations were carried out for first- and second-order irreversible reactions occurring within spherical and slab-shaped pellets. The results are presented graphically in terms of two-dimensionless parameters. 18 refs., 8 charts.

J. D. TINKLER and A. B. METZNER, *Ind. Eng. Chem.*, 1961, **53** (8), 663-8.

Kinetics of the Catalytic Dehydrogenation of Ethanol and Aqueous Solution of Ethanol

The reaction rate ($C_2H_5OH \rightleftarrows CH_3CHO + H_2$) was measured over the range of space velocities 3.0×10^3 to 3.8×10^2 and temperatures 240° to 270°C, using a Cu-Cr catalyst coating the carrier. Taking into consideration the reverse reaction, the following equation, based on partial pressures of the reactant and the products, was derived:

$$r = 3.86 \times 10^{e} - \frac{19720}{RT}\left(\frac{N_{EtOH}}{N_t} - \frac{N_{AcH} \cdot N_{H_2}}{KN_t^2}\right)$$

where $N_t = N_{EtOH} + N_{AcH} + NH_2 + N_{H_2}H_2O$; N_t = total gm moles/gm mole of feed; other symbols refer to the gm moles of the respective substances per gm mole of feed; e = base of natural log; R = gas constant; K = equilibrium constant; r = rate of reaction.

This rate equation was used in operating a pilot plant to test its applicability to the design of commercial reactors. Calculated values agreed closely with results obtained on the pilot plant. 8 refs., 2 diags., 8 charts, 6 tables.

S. YADA and Y. MIHARA, *Chem. Eng., Japan*, 1961, **25** (7), 518-23.

Rigging Techniques for Process Plants

A basic skill such as rigging requires the application of sound engineering principles and ingenuity. This article illustrates modern rigging techniques.

J. P. CHAMBERLAIN, *Pet. Ref.*, 1961, **40** (6), 183-7.

New Developments in Bulk Transport of Chemical Reagents

Several types of vessel used to transport powdered solids are described. These are: (a) air-assisted gravity discharge, with and without blowing equipment; (b) horizontal, fixed fluidized and tipping fluidized pressure vessels; (c) vertical, fluidized and non-fluidized pressure vessels.

R. LEE, *Chem. Engr. (Lond.)*, 1961 (155), A51-A54.

Elimination of Leakage through Refractories by Patching with Powder

Details are here given of a modified method for patching refractories with a high temperature acetylene/oxygen burner which melts ceramic powders. The burner is water cooled and can be used up to 1200°C. A regulated stream of oxygen entrains the powder to the burner.

I. SCHMIDT and M. PUSTAL, *Coke and Chem., U.S.S.R.*, 1961 (1), 35-7.

Some Economic Aspects of Coal Preparation

The U.S. coal industry has continually increased its efforts to market cleaner coal and to deliver a product of ever-increasing dollar value per ton. As a result, over 20 per cent of all raw coal mined is rejected at the mine, and about 65 per cent of all raw coal mined is shipped as mechanically cleaned coal.

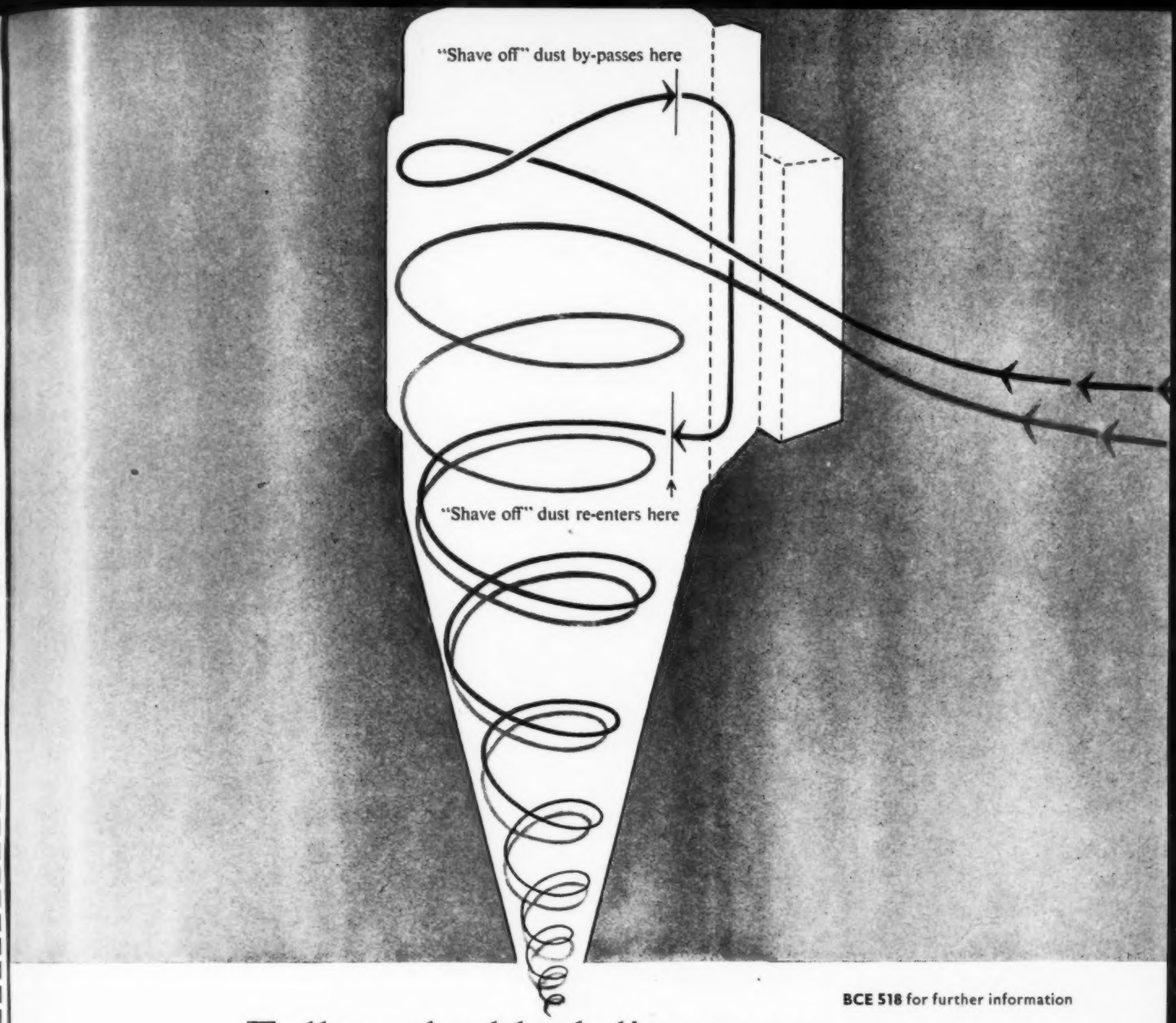
F. R. ZACHAR, *Min. Congr. J., Wash.*, 1960, **46**, 47-53, 59.

Slow Compression Crushing of Single Particles of Glass

Glass cylinders and spheres were crushed by slow compression in a hydraulic press and the elastic energy stored in the specimen prior to fracture was measured. The surface area of the resultant powder was measured in some expts, and the heat generation upon fracture was measured in others. Results show that: (a) considerable additional energy is fed into the fracturing specimen from the press; (b) energy level at fracture varied widely with particle shape; (c) differences occur in crushing effectiveness, that is new surface per unit actual work done on the specimen; these differences are due to the effectiveness with which the stored or feed-in energy is used. 8 refs.

W. J. KENNY and E. L. PIRET, *A.I.Ch.E.J.*, 1961, **7** (2), 199-202.

Brit. Chem. Eng. Abstracts: **FOLIO No. 36**



BCE 518 for further information

Follow the black line to see just one reason why we can **guarantee** the efficiency of every Ambuco Cyclone installation

The AMBUCO method of guaranteed efficiency offers you the following unique advantages:

1. **We analyse** the size, shape, porosity, density, specific gravity, acceleration, etc. of particles and gases to be separated.
2. **We set up fractional efficiency curves** to determine the type of cyclone best fitted to deal with the conditions prevailing in your works.
   This means that every user of AMBUCO "guaranteed efficiency" cyclones can be quite certain of the performance of his dust recovery system *before* an order is placed.
3. **The "shave off"** achieves considerable improvement in the rate of recovery because the dust caught in the "double eddy" current is forced through the "shave off" port (see illustration) and conducted through a by-pass duct down into the main volume of dust.

Dust control is our sole concern. Our engineering and design service is fully equipped to deal with all dust control and recovery problems employing cyclones, scrubbers, grit arresters, fabric dust collectors and other appropriate equipment.

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For technical literature on the Ambuco Cyclones please ring HYDe Park 2178 or write to AMBUCO LIMITED, Standbrook House, 2/5 Old Bond Street, London, W.1.

AMBUCO put dust in its place

ring HYDe Park 2178

A Member of the Gold Fields Mining & Industrial Group.

MINIMUM FLUIDIZATION MASS VELOCITY

by **MAX LEVA** Consulting Chemical Engineer

The nomogram is based on the following equation:

$$G_{mf} = 688\ D_p^{1.82}\ \frac{[\rho_F(\rho_S - \rho_F)]^{0.94}}{\mu^{0.88}}$$

This equation is valid for fluids and solids in general up to such values of G_{mf} that the resulting value of $\frac{D_p G_{mf}}{\mu} < 10$.

G_{mf} will be in lb/hr/sq ft if ρ_F is the average fluid density, lb/cu ft; ρ_S is the true solids density, lb/cu ft; μ is the fluid viscosity, centipoises; and D_p is the particle diameter, in.

The equation has been tested chiefly for relatively uniform solids. However, it will also apply to mixed sizes of a moderate size range. For mixtures the particle diameter is then calculated by $D_p = \frac{1}{\Sigma X/d_p}$

where X is the weight fraction of a size component in a mixture, and d_p is the particle diameter of an individual component.

Problem:

A column carrying a porous plate in its lower section contains a silica sea sand. The sand is of a relatively close size distribution, and the average particle diameter may be taken as 0.005 in. The specific gravity of the sand is 2.65. It is desired to fluidize the sand with air at slightly above atmospheric pressure and 85°F. If the average air density may be taken as 0.075 lb/cu ft, what will be the Minimum Fluidization Mass Velocity?

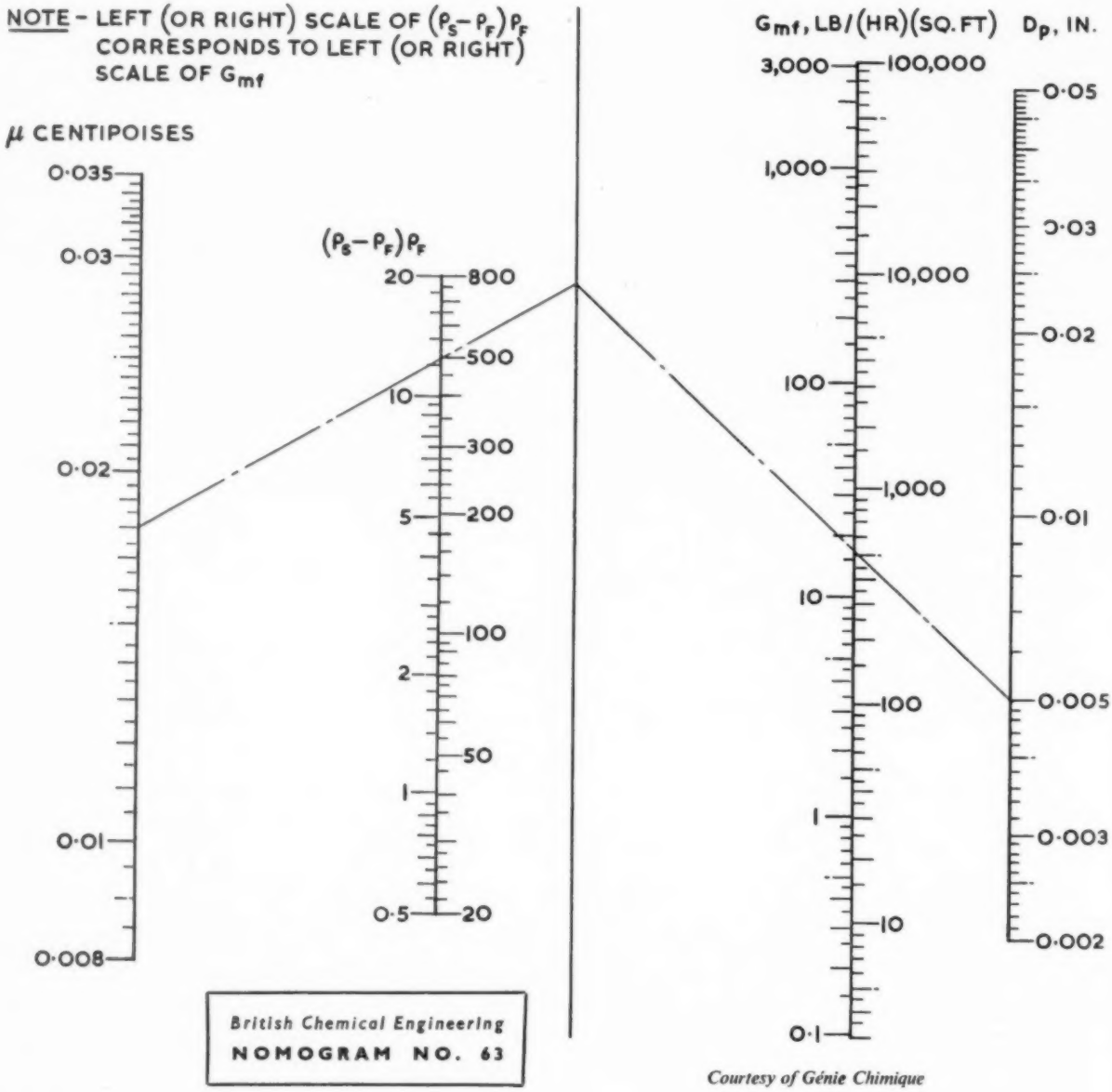
Solution:

$$\rho_F(\rho_S - \rho_F) = 0.075 \times (62.3 \times 2.65 - 0.075)$$
$$= 12.4\ (\text{lb/cu ft})^2, \text{ and}$$
$$\mu = 0.018 \text{ centipoises.}$$

Applying the nomogram yields

$$G_{mf} = 17 \text{ lb/hr/sq ft.}$$

It will be noted from the statement of the problem that G_{mf} is independent of the weight of the bed as well as the diameter of the confining vessel.



British Chemical Engineering
NOMOGRAM NO. 63

Courtesy of Génie Chimique

will not contaminate: resists corrosive fluids: obviously ideal

This new pump by AEI has not just *some* of its 'wet' parts of PTFE . . . but *all* of them! And so—PTFE being chemically inert and impervious to corrosive action—the pump is particularly suitable for corrosive fluids in chemical and industrial processes; and for fluids which must be protected from contamination.

* Pump delivery at 1 ft head is 2 litres per minute; at maximum working head of 15 ft is 1·25 litres per minute, using $\frac{3}{8}$" bore PTFE pipes.
* Diaphragm type, self priming.
* Temperature range: −50°C to +250°C.
* Overall dimensions of pump and motor: Length 10 in. Width 5 in. Height 5 in.

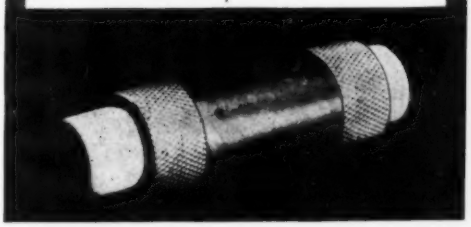
AEI **Associated Electrical Industries Ltd**

Radio and Electronics Components Division
PD17, 155 Charing Cross Road, London W.C.2
GERrard 9797

AND THE

This new coupler—also developed by AEI—enables PTFE tubing to be joined so that only inert and non-contaminating material is exposed to fluids flowing in the tubes. When used with tubing 'belled' ends, there is no restriction in the flow system.

* Will withstand pressures up to 50 p.s.i., even at elevated temperatures (e.g. 100°C).
* Made in five sizes— $\frac{3}{8}$, $\frac{1}{2}$, $\frac{5}{8}$, $\frac{3}{4}$ and $\frac{7}{8}$ in.
* Neat, easy to assemble.



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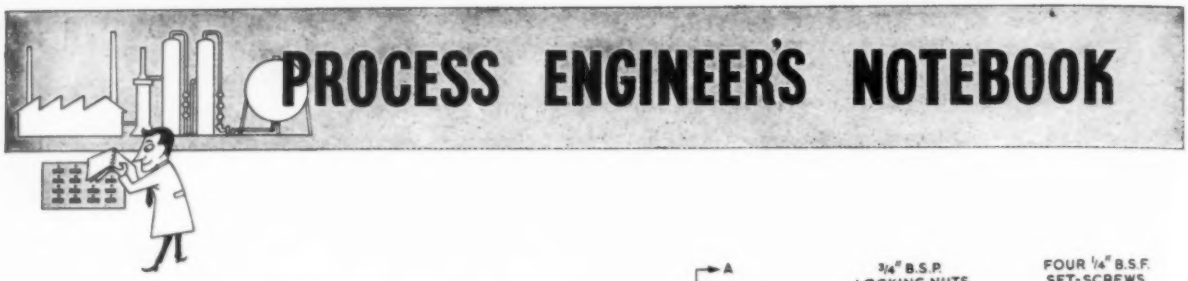


A Universal Connector

A ROTARY valve was to be driven through a variable-speed gearbox. The simplest way of connecting the two was to use a chain drive. However, earlier experience had proved that this method resulted in considerable side-thrust on the valve bearings. It was decided to use an in-line drive. To avoid stresses due to misalignment, a kind of universal coupling was made from B.S.P. M.S. pipe.

Two lengths of 1-in. B.S.P. pipe were cut at the ends so as to provide the interlocking tongues (see Fig. 1). These tongues were bolted by four ¼-in. B.S.F. set screws to an inner ring made from ¾-in. class C B.S.P. pipe. The outside diameter of this ring had to be slightly reduced so as to fit inside the 1-in. pipe.

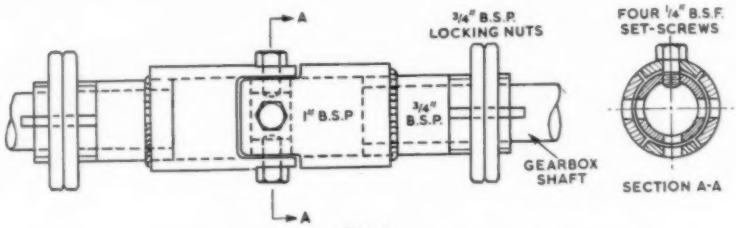


Fig. 1.

Both gearbox and rotary valve shafts were ⅞-in. diameter. These were connected to the coupling through short lengths of ¾-in. class C B.S.P. pipe, threaded at one end; the other end was pushed into the 1-in. pipe and welded. Again a slight reduction of the outside diameter of the ¾-in. pipe was required. Both shafts were cut to take a ¼-in.-wide key. A slot $\frac{7}{32}$ in. wide was cut in the threaded end of the ¾-in. pipe. The pipe (0.866 in. I.D.) was then gently prised open so as to fit over the shaft (0.875 in. O.D.). The pipe slot was then filed so that a ¼-in.-wide key could be tightly fitted. The B.S.P. thread was then approximately cut on the upper surface of the key, in position, by following the contours of the pipe thread with a three-cornered file. The ¾-in.-B.S.P. nuts were then screwed over the pipe, completely locking the assembly to the shaft. A similar technique was employed at the valve end. The coupling proved quite successful at the low speeds required for the rotary valve.

Removable Lagging

A POPULAR method of lagging hot flow lines against heat loss is the use of plastic mixtures of magnesia, etc. The wet plastic is moulded to the shape of the vessel or pipe line together with a wire support, setting hard when dry.

When, however, pipe lengths have to be broken at their unions or valves removed, the lagging has to be chipped away then recast when the unit is replaced.

In an experimental plant a pipe line delivered hot "sticky" solids and was controlled by a slide valve. Blockages in the line meant that this valve had to be removed frequently for cleaning. To save time removing and recasting the plastic lagging around the valve a permanent cast was made in two halves so that it could be removed from the valve without breaking. This cast was made with the valve in position by the use of aluminium foil, the material used for many domestic cooking jobs. The foil itself, with the bright side facing the valve, was first "moulded" by hand to the contours of the bare valve in two halves, leaving about two to three inches of the foil protruding at the joints. The foil becomes quite "crinkly" at this stage but forms an excellent "keying" surface for the plastic lagging when it is cast into the foil cup. Lengths of asbestos tape are set into the plastic to serve as ties for holding the two halves together. With 1-2 inches of lagging moulded around the valve the protruding edges of the foil are trimmed and tucked into the side of the lagging. The holding tapes are tied and there was sufficient grip even in the wet plastic for these tapes to support the casting. When dry this lagging cast was quite robust and was easily removed and replaced, and the reflectivity of the aluminium added to the overall efficiency of the lagging.

Although this technique could be applied to many lagging problems it can only be used for temperatures of up to 500°C.

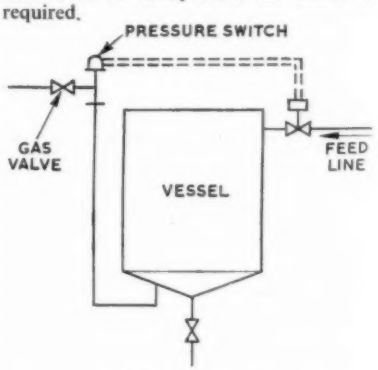
Automatic Level Control

SOMETIMES it is impossible to use float-operated equipment for level control; for example, when the contents of a vessel are being vigorously agitated. To overcome this problem (see diagram), a length of ½ in. dia. stainless-steel pipe connected to the vessel near the bottom and having a "tee" fitting at the other end (i.e., top of the pipe) can be used. A pressure control switch is fitted to the top and a gas valve fitted to the side outlet of the tee. The pressure switch operates a solenoid valve in the feed line of the vessel.

Initially, when the vessel is being fitted the gas valve is kept open and closed only when the required level of liquid in the vessel is searched. After this any level change in the vessel will be immediately reflected as pressure changes at the pressure switch.

An example of its operation is when evaporation lowers the level of liquid in the vessel. When this occurs the pressure drop in the vertical pipe will actuate the mercury switch of the pressure controller, thus energizing the solenoid valve and opening the feed line until the original level is reached. When this takes place the pressure is returned to normal in the vertical pipe and the solenoid valve is de-energized and the feed to the vessel is shut off.

The actual position of the solenoid valve can be as far away from the vessel as required.



Obtaining Fluidization Data in Safety

IN some gas-fluidized processes, toxic or dangerous gases are used for the purpose of fluidizing the solid media. The need often arises to carry out small-scale laboratory work to evaluate basic fluidization data that may be difficult to calculate. For such cases the use of the process gas may be fraught with dangerous risks or necessitate considerable expense in circumventing them. The possibility of using air or some other cheap inert gas in place of the process gas will then become advantageous. The difficulty will be in translating the results of the inert gas experiments into those for the dangerous gas, especially if different temperatures are involved. Under such circumstances, and providing the same solid media is assumed, in apparatus of similar dimensions, the space velocity at fluidization onset of the toxic gas (V_1) will be found to be approximately

$$(\mu_2/\mu_1)V_2$$

where μ_2 = inert gas viscosity;

μ_1 = toxic or dangerous gas viscosity;

V_2 = inert gas space velocity at fluidization onset.

This relationship will apply under differing temperature conditions provided fluidization quality is the same. Bed weight, height and width must be the same. Any consistent units may be used in the above relationship.

P.M.B.

A Gas Sample Filter

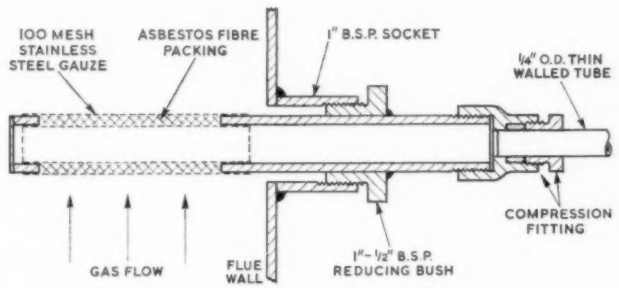
A SIMPLE filter fitting has been designed so that a clean sample could be collected from dust-laden gas at 600°C.

The filtering section was made from concentric cylinders of 100-mesh stainless-steel gauze. The outer cylinder was formed on the outside of a length of ½ in. B.S.P. tube and the seam "brazed". The inner cylinder was made to fit inside the ½-in. B.S.P. tube.

These cylinders were fitted into the end cap, a short length of ½-in. tube sealed with a circular piece of M.S. sheet, and cemented with a heat-resistant cement. Asbestos fibre was then rammed into the annular space between the cylinders, leaving about ½ in. unpacked at the end. A length of ½-in. B.S.P. tube was firmly pushed into this end, further compressing the asbestos packing. The gauze was again sealed to the tube with heat resisting cement.

A 1-½-in. B.S.P. reducing bush was drilled to allow the ½-in. tube to pass through, and when in position was welded to the tube. The filter unit was located in the flue wall by a standard 1-in. socket. The protruding end of the ½-in. pipe was fitted with a compression fitting adaptor to connect with the sampling line.

The filter proved quite efficient and samples were collected quite easily in spite of the relatively low static pressure in the flue, probably with the aid of impact pressure on the filter wall. Solids built up on the forward facing "side" and the filter was occasionally turned in the socket to expose a clean face to the gas flow and periodically totally removed for cleaning.



Leak Testing Chemical Plant

THE well-tried "soap and water" technique of leak-testing vessels and pipework before putting a plant on stream often suffers from the disadvantage of being insensitive to minor leaks such as hairline cracks and pin holes. Under such circumstances, it is necessary to consider more sensitive techniques. Two novel methods that have worked well on an industrial scale have shown a high degree of sensitivity.

One method consists of filling the plant with hydrogen to an air content less than 2 per cent. Plant pressure should be about 10 psi before commencing the test. An industrial explosimeter should then be systematically used to subject the atmosphere close to the plant to an explosive atmosphere test. Leak positions are readily detected by the explosimeter readings which are proportional to the degree of leak. Precautions should be taken during testing to ensure that no hydrogen pockets collect in the plant building by having adequate high-level vents.

Another method consists of filling the plant with ammonia gas to about 5 psi. The entire plant is then sprayed with a weak solution of the pH indicator from cresol green. Leaks from hairline cracks, etc., are shown up as vivid blue marks where ammonia has leaked out and reacted with the indicator.

P.M.B.

Agitator Shaft Protection

COBALT-chromium-molybdenum alloy sleeves fitted to an agitator shaft in a chemical dissolving vessel paid for themselves within two months of their installation and are still in operation some six years later. These were the first of a series of sleeves now in use where spent sulphate liquor is recovered by smelting it and dissolving the residue in large tanks. Agitators mounted on steel shafts mix the burnt liquor.

The sleeves and bushings are mounted in the foot bearing at the bottom of the agitator shaft. The sleeve and bushing assembly protects the shaft from corrosion by sodium sulphide and abrasion by burnt residue that collects in the bottom of the tank. Temperature is about 93°C.

The stellite sleeves, $3\frac{1}{16}$ in I.D. and 4 in. O.D. by 8 in. long, are welded to the shaft. The shaft thus protected turns in the alloy 6K bushings at a speed about 50 rpm. There is no lubrication. A clearance of $\frac{1}{16}$ in. is left between the sleeve and bushing.

Courtesy Union Carbide Corporation.

Contributions Invited

The Editor invites contributions to "Process Engineer's Notebook". They should preferably deal with practical devices designed to overcome problems for which standardized equipment is not available; hints for the improved design of conventional equipment; methods of improving equipment operation; safety devices; etc. For the most meritorious contribution the sum of **10 gns.** will be paid, while other contributors will receive **5 gns.** They will be published anonymously or under the contributor's name, according to his wishes.

Book Reviews

Process Equipment Design (Vessel Design)
by L. E. Brownell and E. H. Young
John Wiley & Sons Inc., New York and London, 1959, 408 pp., 156s.

UNLESS this volume by BROWNELL and YOUNG is to be the first of a series, its general title is somewhat misleading, since the book covers only the design of vessels for chemical plant, both pressure and vacuum, as well as storage tanks, columns, and other related units working at approximately atmospheric pressure. However, it is in many ways an excellent guide to all aspects of this important field.

Various chapters deal with the design of vessels with flat bottoms, conical closures and dished ends; the section on the design of elliptical, hemispherical and spherical closures being the most comprehensive available. Other chapters discuss the design of tall vertical and long horizontal vessels and their supports. The two closing chapters deal with thick cylinder formulæ, autofrettaged vessels, and with the various multilayer vessels: shrunk on, weld shrunk, wire wound, etc. However, although reference is made to MANNING'S work on multilayer cylinders (1947 *et seq.*) this has not been used in their stress analysis—the earlier treatment by COX (1936) being preferred.

Large numbers of examples illustrating each design are interspersed throughout the text, problems are appended to each chapter, and numerous excellent diagrams and photographs are included. (Why is the only illustration of a U.K. installation that of the "... failure of a British storage-tank at Fawley, England"?)

Appendices give a number of charts for determining the shell thickness of vessels under external pressure, properties of sections, properties of pipes, strength of materials, and tables of maximum allowable stresses (the latter being much more comprehensive than in the new B.S. 1500). The book is attractively produced in a large format (quarto), using two columns for text, thus allowing important diagrams to occupy much more space than if the conventional format had been used. The volume fills a need for a comprehensive design manual for pressure, non-pressure and vacuum vessels in the chemical and petroleum industries. Advanced students working on vessel design should find it a mine of information. The reviewer for one will recommend this book, in spite of its price, to his students. W. STRAUSS

Crystallization
by J. W. Mullin
Butterworths, London, 1961, 268 pp., 60s.

CRYSTALLIZATION on any scale remains an art in spite of much theoretical speculation and a variety of experimental observations. On the one hand the theories of crystal growth are barely supported even by the most elegant experiments and on the other hand industry, which operates by means of "lore", is unable to design a process other than by rule of thumb. This book surveys much of the relevant physical chemistry of crystals and solutions in its earlier chapters and concludes with a useful summary of the ancillary problems of size and size distribution analysis.

The chapters which could have attempted some unification of the unit operation aspect of crystallization, by attempting some correlation between theory, small scale experiments and plant operation, are an uncritical review of the literature. Most of the publications concerning the mechanism of growth are listed and there follows an entirely descriptive survey of industrial plant. As a survey the book fulfils its objective but an attempt to indicate how crystallizer design might be approached could have emphasized at least those points at which the subject still requires attention.

G.H.B.

Beispiele und Übungsaufgaben zur Chemische Verfarhrenstechnik
by Pawlow, Romankow and Noskow
VEB Deutscher Verlag, Leipzig, 1960, 549 pp., DM 32

THIS is a German translation from a Russian third edition of "Examples and Problems on Chemical Process Engineering". This original book has been sponsored by the Leningrad Technological Institute as a supplement to the "Chemical Process Engineering" by KASSATKIN. The authors state that their objective was to provide practical examples on the design of chemical plant, so that students could develop their skill and confidence in handling numerical problems. This objective is fulfilled admirably and the book will also fulfil most lecturer's dreams in providing over 200 ready made worked examples and additional 300 problems with answers given in the appendix. The appearance of an equivalent publication in English language is long overdue. The sporadic illustrative examples which can be found in some text-books are inadequate to supply sufficient material for practical exercises and the preparation of such examples is a tedious and time consuming process.

The subject matters covers practically the whole of the chemical engineering field and includes hydraulics, mechanical separations, heat transmission, evaporation, crystallization, distillation, absorption, drying and refrigeration. The arrangement follows that of KASSATKIN'S text-book and thus supplies examples to each subject separately. Each chapter begins with a summary of relevant formulæ with explanations on their validity and limitations. This is followed by numerous illustrative examples and problems. An appendix of over 70 pages contains tables, diagrams and nomograms with physical data necessary for the solution of the problems. Special care is taken to explain the use and conversion of units, including British units.

It is interesting to note that with a few exceptions, the approach and treatment of design problems does not differ from that found in the English text-books. The old and familiar formulæ are all there, may be slightly rearranged, modified or renamed. There are a few unfamiliar dimensionless groups, e.g. Ljastschenko or Kirpitschew, but one can hardly notice any sign of the existence of an iron curtain were it not for the rather strange absence of references to any western publications with the exception of PERRY and MCADAMS. This omission has been corrected to some extent by the inclusion of an additional list of references in the German translation. This shortcoming does not detract from the value of this book which can be warmly recommended to the teaching profession, students and junior chemical engineers.

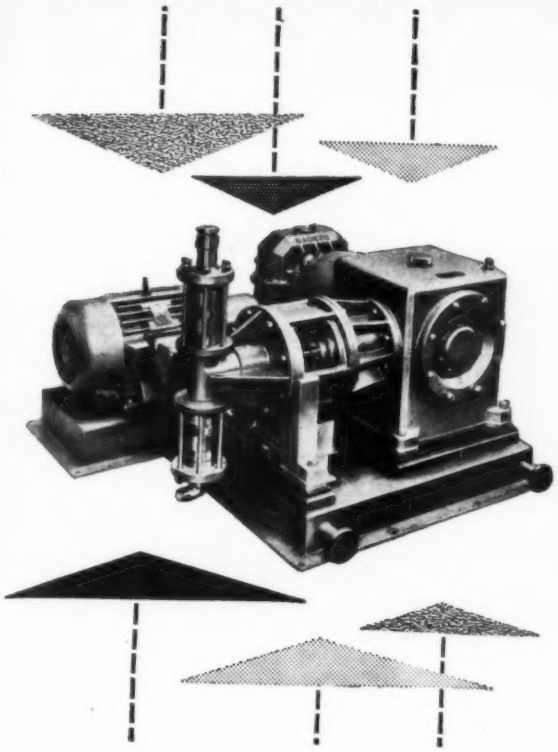
Chemical Process Principles: Part II: Thermodynamics (2nd Ed)
by O. A. Hougen, K. M. Watson and R. A. Ragatz
John Wiley & Sons Inc., New York and London, 1959, 567 pp., 78s.

TO present the first stage of chemical process development as a whole, HOUGEN and WATSON gave the title of "Chemical Process Principles" to their three-part text-book—the volumes dealing with material and energy balances, thermodynamics, and kinetics and catalysis. Originally each part was comparatively small and at one time the three were published together as one volume. The parts are now being revised and republished with an additional author, R. A. RAGATZ. Part II (Thermodynamics), which appeared recently, is almost twice the size of the original volume and has been considerably extended in scope, particularly fluid flow which now includes flow at supersonic speeds and compressible flow from nozzles and through ducts; while power generation also has sections on gas turbines, free piston engines, turbojets, ramjets and rockets.

The section on generalized properties of fluids, for which the first edition was notable in its treatment, has been further improved by the introduction of a third parameter with the presentation of tables covering both gas and liquid phases based on available p-v-T data of 82 different compounds. Using these tables should enable p-v-T data to be estimated without the use of complex equations (with up to 8 variables). Other new sections deal with separation processes, solubility and absorption, and complex reactions The omission of the chapter on the calculation of thermodynamic properties from molecular structure is to be regretted, as this has been the only place where, using simple language, the basic structural partition functions and bond energies (which are usually considered the domain of the theoretical chemist or chemical physicist) could be turned into useful thermodynamic data for those compounds for which no experimental values were available.

Together with a new type-face, improved setting out, and better paper and binding, the new volume is much better than its predecessor—although unfortunately the price has also more than doubled. It still remains a book to be recommended to the student and design engineer. W. STRAUSS

BCE 520 for further information



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This is the metering pump we recommend for clear corrosive liquids, for alkaline suspensions, for boiler feed conditioning reagents. There are other uses, too, of course, which our highly-trained representative will explain if you ring EALing 6264 and ask him to come along to see you. In the meantime, jot down these very brief points about this new Metricon pump, type 'W'. It is a reciprocating pump with a fixed length of stroke of 2¾ inches. A variable speed gear can be supplied so that the pump stroking speed can be varied manually, electrically, or pneumatically. Flame-proof or weather-proof motors as well as screen-protected machines can be supplied. (This pump is an addition to our already extensive range of metering pumps). Asking our representative to call, means not the slightest obligation, of course.

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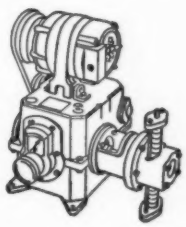

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What's going on here?

A North PVC apron, for safety's sake

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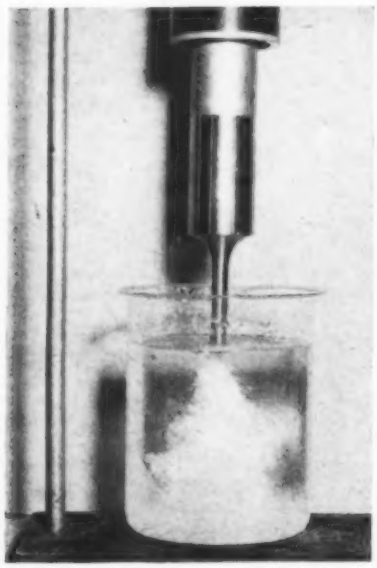
PLANT EQUIPMENT NEWS

Ultrasonic Emulsifier



A small-scale emulsifier has recently appeared on the U.K. market in the form of a new ultrasonic device, the S-75 Sonifier. The principle of the apparatus is the conversion of high-frequency electrical energy, supplied by a 75-watt generator, into 20-k/c ultrasonic vibrations. Efficient emulsification or dispersion is obtained by selecting one of eight possible power levels, and immersing the tool bit in the liquid for a short time. The generator, which is housed in an aluminium cabinet, measures 13 × 9½ × 5 in., and weighs only 20 lb.

In addition, two other designs can be supplied: one is a new laboratory tool developed for dispersing materials which are otherwise difficult to wet out, or for emulsifying liquids which are normally immiscible; the other, which uses intense ultrasonic energy, is suitable for breaking oil films into minute droplets. It produces emulsions and dispersions which are normally considered impossible. **Branson Europa N.V., Industrieweg 14, Loosdrecht, Netherlands.**

BCE 569 for further information

Calculating Machines

A number of German-made calculators are now available to the home market. The three models of the "Mercedes" range, which have 20 digits on the keyboard, are Model RSM 44—£350, RSM 43—£310 and R40—£180. The "Triumphator" Model KN (£25) has seven setting levers, five digits on the counter register and eleven digits on the product register. **Broughton & Co. (Bristol) Ltd., 6 Priory Road, Bristol, 8.**

BCE 570 for further information

Loaded PTFE Pump Bearings

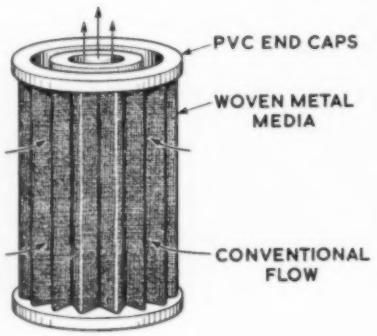
Appleton & Howard are now in a position to fit submerged pumps with loaded PTFE bearings, with the loading in ceramic powder, stainless steel, nickel, glass and carbon; the latest possibility is I.C.I. "Fluon" PTFE loaded with titanium.

Chemical Engineers will appreciate that the availability of a wide range of bearing materials, with such highly corrosion-resistant properties, gives the submerged type of pump added advantages. One of the problems with a pure PTFE sleeve bearing has been its bad cold flow habits, mainly due to the local heating effect of the rotating shaft (especially at 2885 rpm), a tendency reduced by loading PTFE; but, in addition to this, sleeve bearings in the GUSH series of submerged pumps are designed to behave as small heat exchangers, so that bearing temperatures are uniform, irrespective of the liquid level in a vessel. This design also eliminates the cold flow effect.

All GUSH pumps are fitted with I.C.I. "Fluon" PTFE washers as a seal between the tail end nut and impeller and between impeller and shaft sleeve to prevent the corrosive attacking the high tensile shaft core. **Appleton & Howard Ltd., Salisbury Street, St. Helens, Lancs.**

BCE 571 for further information

Pleated-element Liquid Filters

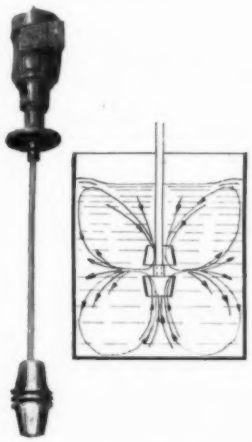


An entirely new range of filters and filter cartridges makes use of pleated, woven fine-mesh filtering media made from either phosphor bronze, monel or stainless steel. The filters using this material are capable of separating particles down to 23 microns. This development is based upon the experience of filtration with the Locker company's existing disc type filter and it makes use of built-in PVC or epoxy resin sealing which permits the manufacture of an economical filter. **Locker Industries (Sales) Ltd., Warrington.**

BCE 572 for further information

Twin-cone Mixers

This type of mixer has an impeller consisting of two cones mounted on the same shaft with the apices remote from each other. During agitation the fluid flows from the smaller diameter end to the larger diameter end of the cones, and it is sheared between the gap separating them.

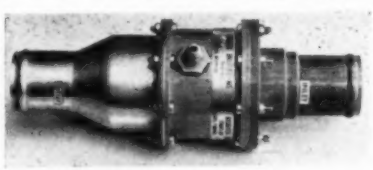


The mixers are capable of emulsifying and dispersing almost any substance, including gas in fluids. They are made in a variety of sizes, from a laboratory model 30 mm in diameter to 246 mm in diameter for larger installations up to 30 m^3 capacity. **DOSAPRO, 3 rue d'Edimbourg, Paris-8e, France.**

BCE 573 for further information

Vent Valve for Pressure Control in Fuel Systems

The R.V.63 is a new dual inward/outward vent valve for use in the pressure control of tanks in fuel systems. Developed primarily for the aircraft industry, it could find applications in the chemical industry. The inward venting is controlled by a lightly-spring-loaded diaphragm and the valve passes 20 cfm with a pressure drop of 0.3 psi. Coaxially, the outward relief valve is spring-loaded and has a nominal flow-off pressure of 3 psi and a 6 cfm air flow at 3.4 psi back pressure. During fuelling operations the outward relief vent is held open and 35 gpm may be passed. It weighs 1¼ lb and is fitted with 1¼-in. beaded connections.



The Hymatic Engineering Co. Ltd., Redditch, Worcs.

BCE 574 for further information

SUPER-D-HYDRATOR

"Keep it under your sombrero, Señor"

"I have news from across the border, Señor, brought by my special messenger service on a Mexican Eagle. People are saying that Sharples not only make super centrifuges, but also provide a full consultative chemical engineering service on any separation project. I am a poor man Señor. I speak only the truth."

SHARPLES - *chemical engineers as well as makers of centrifugal equipment*

P24A

Sharples Centrifuges Ltd · Tower Works · Doman Road · CAMBERLEY · Surrey Telephone: Camberley 2601 Telegrams: SUPERSPIN, CAMBERLEY

PLANT EQUIPMENT NEWS

Square Batch Mixer

In this mixer the material to be mixed is discharged from the worm along its entire length, and is thrown against an angular-shaped housing.

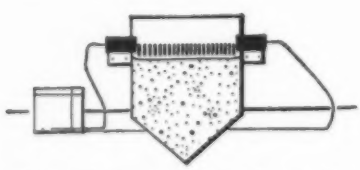
Tests with silicates with a particle content of about 1-100,000 show that the average mixing time is approximately 17 min.

The mixers are available, ex stock, in capacities ranging from ½ ton to 5 tons. **E. R. & F. Turner Ltd., Foxhall Works, Ipswich.**

BCE 575 for further information

Versatile Ultrasonic Process Control System

A completely new sensing and switching system, the Westool Sonac, is expected to have wide applications in industry for automatic counting, level control and numerous other operations. The system uses an ultrasonic sound beam and will detect solids or liquids, opaque or transparent objects, ferrous or non-ferrous metals. The beam, which is inaudible and invisible, can be made several feet wide or will work through holes down to about 0.03 in., and it can be made to go around corners by piping it through a tube. Thus the unit itself can be remote from its sensors.



In use for automatic level control.

It can be used for automatic weighing, size control, cut-off control and hopper and bin level control (illustrated). The circuits are completely transistorized and the two sensors are of hermetically-sealed pod construction. The temperature operating range of the sensors is −350°F to +220°F. **Westool Ltd., St. Helen's Auckland, Co. Durham.**

BCE 576 for further information

Pyr-O-Volt Proportional Controller

A new low-cost proportional controller for controlling electrical loads with magnetic amplifier and saturable core reactor is available. Known as the Pyr-O-Volt 105R12, this instrument, in addition to indicating electrical loads, will also control saturable core reactors up to 100kVA, with provision for control of larger reactors.

Features are straight line control, automatic fail-safe and built-in voltage regulation.

A millivoltmeter indicator (105X11) which has a high-quality moving-coil movement, is also available. **Honeywell Controls Ltd., Greenford, Middlesex.**

BCE 577 for further information

Shaw Hygrometer Alarm

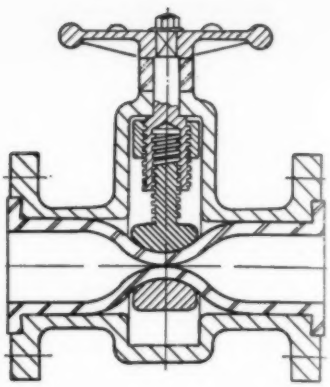
A new ultra-sensitive alarm for moisture in gas or air contains a transistorized relay which operates the alarm or control contacts. The dial may be scaled from −120°C to −20°C dewpoint or in per cent humidity, as desired. The response to humidity change is immediate and the instrument works in liquids containing a small amount of water (kerosine for jets). It requires no maintenance and its maximum temperature rating is 180°C. Available from stock for £200 complete with sensing element. **Shaw Moisture Meters Ltd., Bradford, England.**

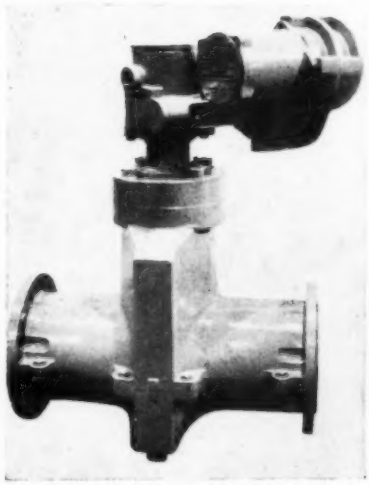
BCE 577A for further information

Motorized and Pneumatically-operated Pinch-type Valves

The highly developed range of Linatex pinch-type valves has now been expanded to embrace motorized and pneumatically-operated types. After considerable experience with the standard hand-wheel-operated valve in sizes from ½- to 8-in. bore, these have now also been extended to include 10-, 12- and 14-in. bores. As is well known, the pinch-type valve has the merit of giving full-bore unrestricted flow when open. This makes it ideal for handling slurries and powders. The valve is glandless and the basic design greatly facilitates maintenance, since it is necessary only to change the rubber sleeve to restore the valve in as new condition. The quality and performance of the valve sleeve require to be of a very high standard.

In most cases, especially when handling abrasive slurries or powders, the sleeve is made from Linatex rubber as incorporated in pumps, pipelines and other material handling equipment. For handling chemicals the valve is fitted with sleeves made from an appropriate synthetic rubber material and these include butyl, nitrile, hypalon and neoprene as dictated by the working conditions. A range of non-return valves and safety/relief valves is also available.





A full-bore, straight-through flanged-type valve is illustrated in the drawing and a motorized valve is illustrated in the photograph. A comprehensive technical booklet, which gives details of the new range of valves and the various operating systems, is available free on request from **Wilkinson Rubber Linatex Ltd., Camberley, Surrey.**

BCE 578 for further information

New Acrylic One-coat Finish for Metal Surfaces

Armacryl, a new acrylic one-coat finish for metal products and equipment of all types, is suitable for the finishing of domestic appliances, photographic equipment, switch boxes, safes and equipment used in conditions of frequent condensation and high humidity.

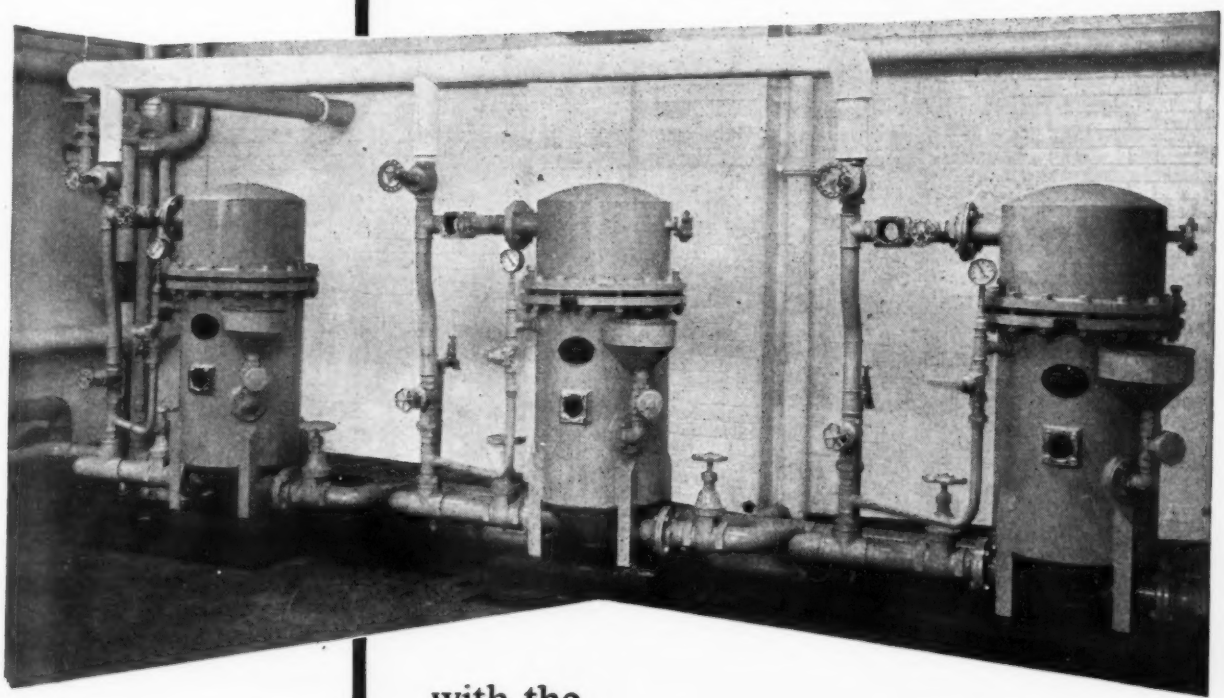
Being resistant to staining and chemicals, ink and dyestuffs, it can be applied on operating theatre and general medical equipment, catering and food manufacturing appliances and machinery, chemical

BCE 523 for further information

SAFEGUARD YOUR LIQUID ASSETS

Liquid assets in the shape of edible juices and industrial fluids, chemical solutions, oils and spirits are too valuable to be wasted. They need the Stellar Filter to safeguard them, to render liquid loss almost negligible whilst clarifying and purifying. Designed to operate with supreme efficiency, the Stellar Filter has an unchokeable filter bed and is perfectly simple to control. It is remarkably economical, too, for it can be cleaned without dismantling or loss of liquid, and occupies very little ground area.

Tell us your problem and we'll gladly advise you how and why the Stellar Filter will take good care of your liquid assets.



* *They may be: WAXES—OILS ESSENCES—WINES—SPIRITS JUICES—CHEMICALS PHARMACEUTICALS SYNTHETIC RESIN SOLUTIONS SOLVENTS—VARNISHES INDUSTRIAL FLUIDS—and, of course, WATER*

with the

STELLAR FILTER

...another **Paterson** *design for purity*

Effluent and Water Treatment Exhibition, Stand No. 43

THE PATERSON ENGINEERING CO. LTD., 129 KINGSWAY, LONDON, W.C.2

PLANT EQUIPMENT NEWS

balances, bobbins, hosiery manufacturing machinery, photocopying machines and oil-burning plant.

It is ideal for tropical and semi-tropical climates.

The outstanding properties claimed are humidity resistance; hardness; resistance to colour change on heating, over-stoving, or exposure to exterior weather conditions; chemical resistance; grease, stain and detergent resistance; flexibility and impact resistance; and adhesion.

These properties are all obtainable with a one-coat application on steel, without primer (which latter need only be used if the metal surface is poor and needs filling). It can also be applied directly to Zintec and the results are greatly superior to those usually obtained, but aluminium may require chemical pretreatment of the Alechrome type if the surface is highly polished. Application can be by spraying or dipping, and stoving by convection should be for a minimum of 300°F for 30 min. **Griffiths Bros. & Co. London Ltd., Armour Works, Well Lane, Wednesfield, Staffs.**

BCE 579 for further information

Series 270 Colloid Mills

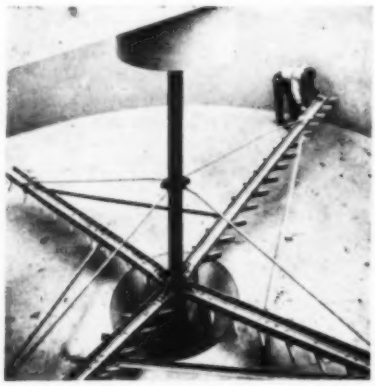
A new range of colloid mills has been designed for the rapid processing of emulsions, suspensions and dispersions. In these, the product passes through the mill in an unbroken film under hydrostatic pressure, thus completely elminating the tendency to aerate the product. Three models are available having outputs from 250 to 3000 gph. **Apex Construction Ltd., 15 Soho Square, London, W.1.**

BCE 580 for further information

New Thickener for Corrosive Effluents

Compactness and greater efficiency are claimed for this 30-ft-diameter thickener installed at the new Bedford plant of manufacturers of semi-conductors. The thickener is used on the neutralization stage of the effluent disposal system. This effluent is extremely complex and contains a wide range of corrosive chemicals.

The unit's compactness is due to the machine-cut involute/helicoidal worm gears which have very high efficiency. With this worm gear drive the tooth loading is much higher than the loading on large cast wheels. This enables more compact worm wheels to run in a totally enclosed oil bath. As a result, operation is silent and hardly any maintenance is required apart from routine greasing and oiling.



The manufacturers are now designing a completely automatic system for lifting the rakes. The unit has been designed with the export market in mind; it can be partially dismantled for shipment and easily assembled abroad with a minimum of skilled supervision. **Chemical Equipment Engineering Ltd., Macclesfield.**

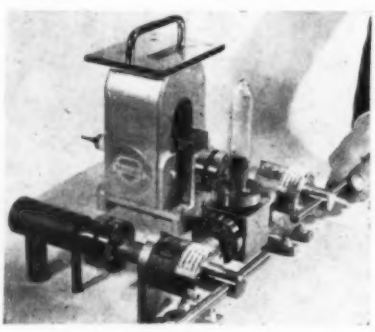
BCE 581 for further information

Ultra High Vacuum Device

This pump is based on the principle of the Penning gauge, in which electrons are made to oscillate between cold cathodes. A magnetic field perpendicular to the direction of electron flow causes the electrons to traverse spiral paths as they oscillate in the electrostatic field formed by the cathodes and the anode. Ions produced by these electrons are accelerated to the cathodes and liberate more electrons, the combined action being self-supporting.

The VPP-5 pump comprises many Penning electrode units in parallel using common titanium cathodes on each side of a nest of anodes. During operation, the titanium sputters from the cathode on to the anodes, forming fresh surfaces which getter very actively. The life of the pump is dependent on the amount of titanium available at the cathode for sputtering and is estimated to be 10,000 hr at a pressure of 10^{-6} torr.

The pumping action will begin at a pressure of 5×10^{-2} torr and continue until a pressure as low as 10^{-11} torr is reached. Over this range the pumping speed for air is 5 l/sec.



Characteristics

Pumping range ...	5×10^{-2} to 5×10^{-11} torr
Pumping speed (air) ...	5 l/sec
Fore pressure required to start pumping operation	5×10^{-2} torr

Over the operating range of the pump the pumping speed is independent of pressure but varies with different gases.

Limiting Values

Maximum operating temperature ...	250°C
Maximum bake-out temperature ...	500°C

Power Requirements

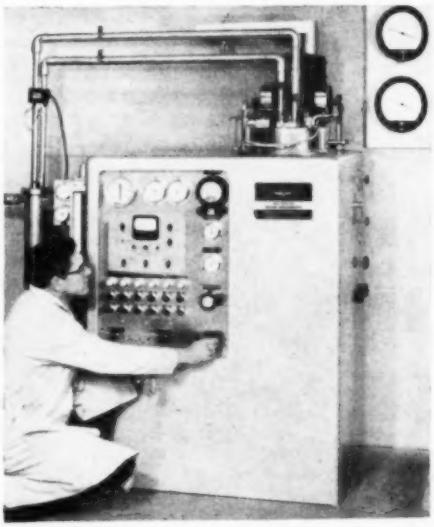
Open circuit voltage ...	3.0 kV
Maximum load current	300 mA

Mullard Ltd., Torrington Place, London, W.C.1.

BCE 582 for further information

Helium Refrigerator

The ADL-Collins helium refrigerator is a complete low-pressure installation which may be used to provide cold gas refrigeration at temperatures as low as 8°K. The unit may also be used for liquefying helium when no refrigeration is required.



This refrigerator has many applications in cryogenic research, such as cryopumping, cooling samples in reactors, refrigerating hydrogen bubble chambers and liquefying helium.

It is a modification of the ADL-Collins helium cryostat which, after fourteen years, continues to be the accepted basic tool of low-temperature research throughout the world. **Arthur D. Little Inc., Acorn Park, Cambridge, 40, Mass., U.S.A.**

BCE 583 for further information

Industrial Gas Meters for 100 psi

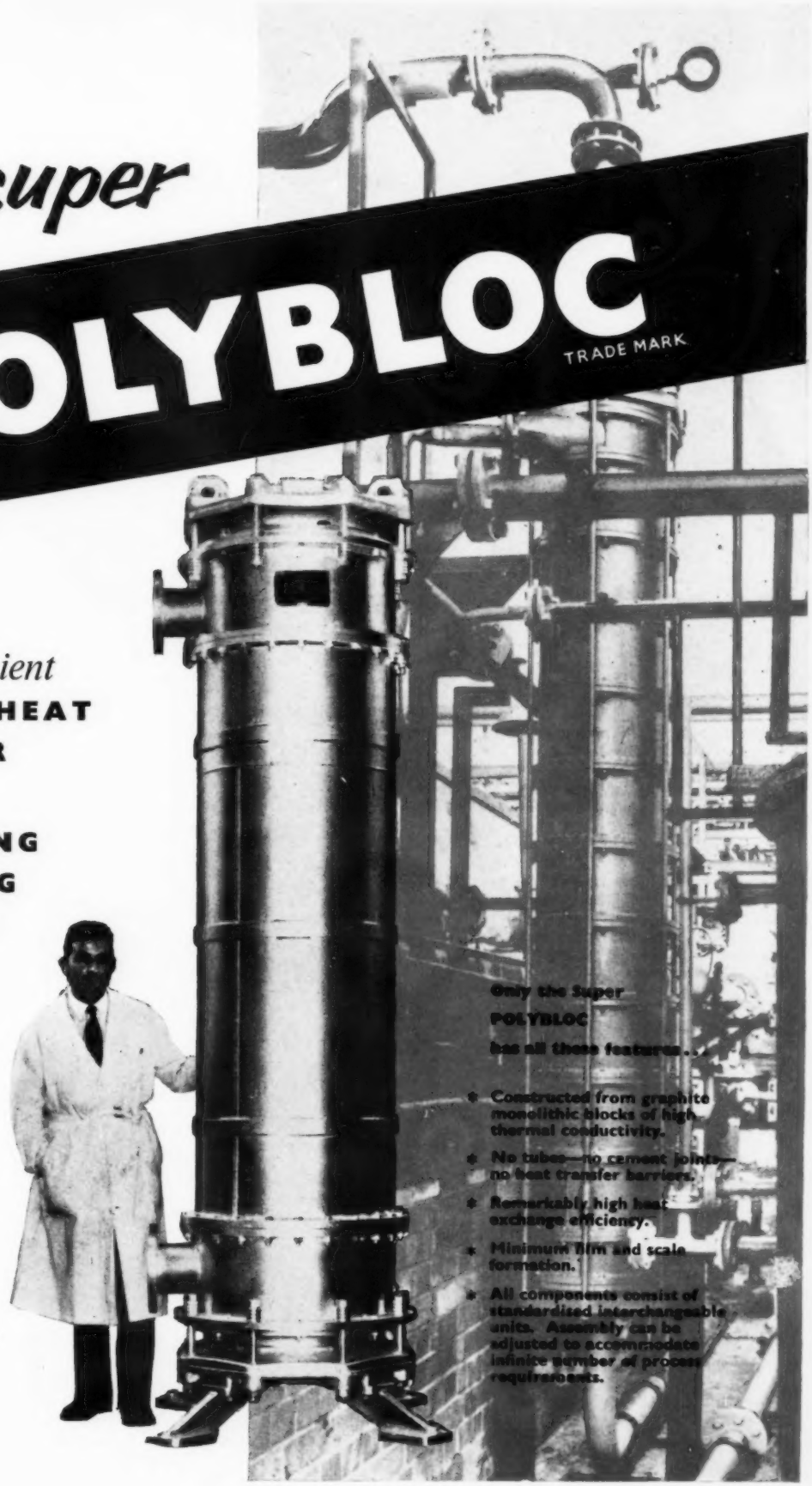
Two new industrial gas meters operating at up to 100 psi are now made and marketed in the U.K. Capacity per revolution

the super

POLYBLOC

TRADE MARK

The most efficient
GRAPHITE HEAT EXCHANGER
in the world
FOR HEATING OR COOLING CORROSIVE FLUIDS



Only the Super POLYBLOC has all these features...

- Constructed from graphite monolithic blocks of high thermal conductivity.
- No tubes—no cement joints—no heat transfer barriers.
- Remarkably high heat exchange efficiency.
- Minimum film and scale formation.
- All components consist of standardised interchangeable units. Assembly can be adjusted to accommodate infinite number of process requirements.

ROBERT JENKINS
& CO. LIMITED
ROTHERHAM

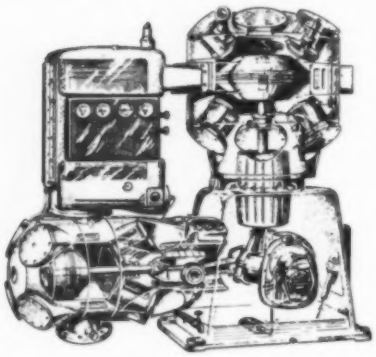
Telephone 4201-6 (6 lines)

PLANT EQUIPMENT NEWS

of the B 1200 model is 0.5 cu ft, and that of the B 2000 model is 1.25 cu ft. Capacities of the B 1200 and B 2000 at 0.5 in. wg pressure loss are 1000 and 1500 cu ft respectively on air. At 2.0 in. wg pressure loss the capacities are 2000 and 3000 cu ft respectively. Both meters register up to 10 million cu ft and are fitted with a 10 cu ft test dial. **Parkinson Cowan Gas Meters, 52 Grosvenor Gardens, London, S.W.1.**

BCE 584 for further information

"L" Form Stationary Compressor



This two-stage, double-acting, water-cooled, stationary compressor with LP and HP cylinders arranged in "L" form has a capacity of 2225 cfm (63 m³/min) f.a.d. It is simple, cheap to install, compact, light, inexpensive to operate and maintain, and requires little cooling water.

The ER8 has double-acting pistons made in the form of a truncated cone, a short piston stroke and comparatively high speed. These features give the unit a remarkably low size/capacity ratio. **Atlas Copco (G.B.) Ltd., Maylands Avenue, Hemel Hempstead, Herts.**

BCE 585 for further information

Automatic Tank Welding Equipment

The Rockweld "Arcos" Circomatic welding equipment can achieve a welding speed of approximately 24 in./min on ¼-in. plate.

The machine weighs 30 cwt and runs on the upper edge of each ring of plates.

Two arcs are simultaneously used, one inside and the other outside the tank. The machine will weld up to ⅞-in. plate in a single pass.

The equipment has been satisfactorily used in the construction of tanks on the Purfleet site of Shell-Mex & B.P. Ltd. **Rockweld Ltd., Commerce Way, Croydon, Surrey.**

BCE 586 for further information

Centrifugal Pumps

A new range of compact, close-coupled centrifugal pumps for general use has been developed which are of all-ferrous construction and suitable for mild chemical services. These "G.S." Mopumps have single entry, single impeller and are fitted with a mechanical seal. They are designed to fit the new compact motors to the dimensions of B.S. 2960, Parts I and II, in which either drip-proof or totally-enclosed motors are interchangeable. Further, the pumps can be opened for maintenance without disconnecting the pipework or lifting the motor.

Twenty-nine pump sizes, ranging from 1 to 5-in. branch size, provide a comprehensive choice of pump and motor combination. **Rhodes, Brydon & Youatt Ltd., Reddish Engineering Works, Stockport, Cheshire.**

BCE 587 for further information

Titanium Centrifugal Pumps

A range of horizontal pumping sets is now available in the GUSH series with heads from 10 to 150 ft and capacities from 2 to 1000 gpm. All wetted parts are in solid titanium and in all these units either packed glands or Crane type 10 mechanical seals are available. Where abrasive solids are present and a packed gland must be used, the titanium protective sleeve at the gland is coated with a minimum of 1 mm of ceramic. **Appleton & Howard Ltd., Salisbury Street, St. Helens, Lancs.**

BCE 588 for further information

Logarithmic Electronic Recorder

A British-designed electronic strip chart recorder, with alternative logarithmic or linear response, intended mainly for research applications is to be made by Honeywell Controls Ltd. at Newhouse, Lanarkshire.

The recorder has two slidewires. One is included in the measuring circuit and obeys a logarithmic law with better than 0.4 per cent accuracy; the other is of linear construction.

The new recorder has a calibration accuracy of better than 1 per cent, but, to maintain a repeatable accuracy of 0.25 per cent over the full scale, the minimum span is restricted to 5 mV. **Honeywell Controls Ltd., Greenford, Middlesex.**

BCE 589 for further information

New Publications

New Data on Acrylonitrile. A new 25-page booklet (Ref. Rf-8381B) has just been introduced by Union Carbide.

Included is information on physical properties; reactions; applications; specification limits; test methods; storage, handling and shipping; toxicological properties; and selected literature references. Because of the double bond and nitrile group, many paths of chemical modification are possible. As a monomer or comonomer for synthetic textile fibres, acrylonitrile allows polymeric materials to form oriented fibres. Rubber elastomers produced from acrylonitrile copolymers are resistant to heat, chemicals, solvents and weather. Acrylonitrile also undergoes many reactions to yield solvents and plasticizers; and to yield intermediates for dyes, pharmaceuticals and insecticides. **Chemicals Department, Union Carbide International Co., New York, 17, U.S.A.**

BCE 590 for further information

Sulphuric Acid and Related Chemical Plant. This 12-page brochure describes and illustrates the following types of sulphuric acid and related chemical plants which are available through The Power-Gas Corp. Ltd.

Plant for the manufacture of sulphuric acid from any sulphur-bearing raw material such as sulphur, pyrites, hydrogen sulphide, sinter and other SO_2 gases, spent oxide, gypsum, etc.

Plants for the production of phosphoric acid from sulphuric acid and phosphate rock and triple superphosphate from phosphoric acid and phosphate rock (S.I.A.P.E. process).

Liquid sulphur dioxide from SO_2 gases by the pressure absorption process.

Plant for the concentration of sulphuric acid.

Mechanical-type muffle furnaces for the production of alkali sulphates and hydrochloric acid. **The Power-Gas Corp. Ltd., P.O. Box 21, Stockton-on-Tees, Co. Durham.**

BCE 591 for further information

Prevok Rust Preventive. A 5-page brochure describes Prevok, a rust preventive based on wool fat derivatives dissolved in a volatile solvent. It does not separate into its component parts even after long storage and is available in several grades containing 20, 30/35 or 40 per cent total solids.

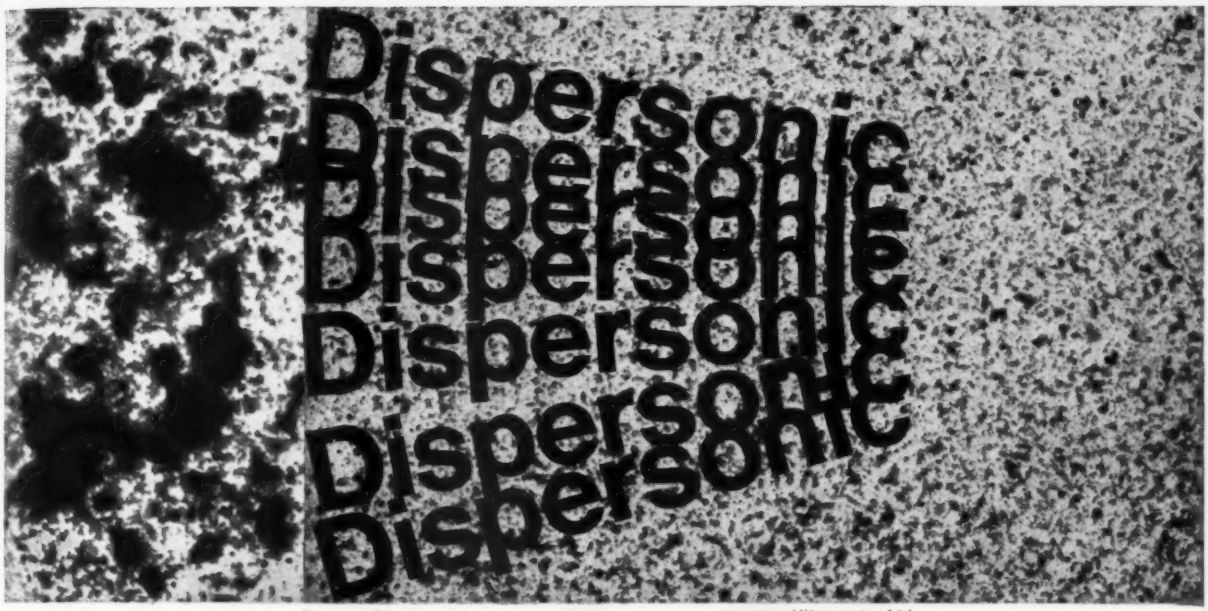
Prevok can be sprayed or brushed. It has a flash point of 118°F and is regarded as inflammable. **Croda Ltd., Cowick Hall, Snaith, Goole, Yorkshire.**

BCE 592 for further information

Newman Velan Valves. A 16-page illustrated brochure contains complete details of the Newman Velan bonnetless valves, which are primarily designed and built for extreme temperatures and pressures.

Flow chart nomograms are included for air, steam and water. **Newman, Hender & Co. Ltd., Woodchester, Stroud, Gloucestershire.**

BCE 593 for further information



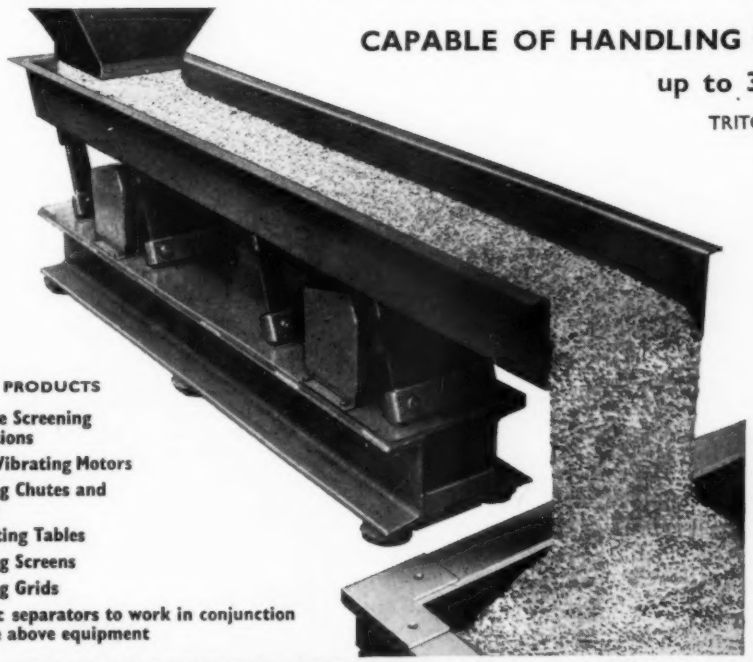
The new Dispersonic is designed for really fast dispersion of powders in liquids. It uses the patented principle of the liquid whistle by which the material itself supplies cavitational energy for the process.
If you want to prepare your suspensions more quickly and cheaply, please write for full details or visit our laboratory.

Ultrasonics Ltd

Westgate Otley
Yorkshire
Telephone Otley 3221

Wilson

*TRITON VIBRATORY CONVEYORS



CAPABLE OF HANDLING from a few ozs. per hour up to 30 tons per hour or more

TRITON Vibratory Conveyors and Feeders are manufactured in various sizes, to handle capacities from a few pounds to several tons per hour, of materials ranging from fine powder to quarry stone, etc. The electrical control unit supplied with these feeders enables perfect capacity control of the material being conveyed. These machines can be supplied complete with storage hoppers and supporting structures, which can be constructed to suit your own particular requirements. They are also ideal for use in conjunction with automatic weighing machines, screening plants and laboratory work. SPECIAL shaped Feeder Troughs, for example, 'V' section, tubular or half-round, can be fitted to the standard feeder units, if required.

OTHER PRODUCTS

- Complete Screening Installations
- Rotary Vibrating Motors
- Vibrating Chutes and Hoppers
- Compacting Tables
- Vibrating Screens
- Vibrating Grids
- Magnetic separators to work in conjunction with the above equipment

Please note our change of address

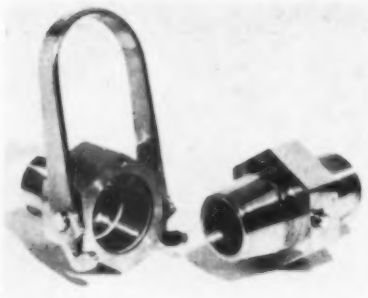
THE TRITON ENGINEERING CO (Sales) LTD Kingsnorth Industrial Estate, Wotton Road, Ashford, Kent Telephone: Ashford 2051 (5 lines)

in association with Triton Engineering Co. Ltd.

* "TRITON" is a registered Trademark

PLANT EQUIPMENT NEWS

New Quick-disconnect Coupling



This new coupling was developed for use with liquid oxygen and nitrogen. The device is simple to connect and disconnect and very sturdy. The oxygen and nitrogen couplings are keyed differently so that the possibility of erroneous connection is eliminated.

The coupling consists of a male and female tapered connector which form a leakproof seal when locked in position with a yoke-type lever. **Cryogenics Inc., Stafford, Virginia, U.S.A.**

BCE 594 for further information

Liquid Level Controller

This controller, known as the "Resistion", is intended for use with any conducting liquid provided the resistance does not exceed 50,000 ohms/cm^3. It is ideal for controlling the level of water in feed tanks. In conjunction with a high-temperature electrode, it can be used for boiler level control and will give audible and visual alarm as well as taking corective action when the water in an unattended boiler has fallen to a dangerous level. **Thomas Industrial Automation Ltd., Altrincham, Cheshire.**

BCE 595 for further information

Self-priming Pump for Volatile Liquids

These pumps are of the regenerative type, self-priming on the liquid ring principle. The regenerative turbine creates an internal circulating effect within the pump casing which enables each pump stage to develop about six times the head of a conventional centrifugal pump having an impeller of equal peripheral speed. The number of stages required to produce a given head is reduced and high heads are possible at speeds of 1450 rpm.

The dynamic suction lift is 28 ft and the pump will evacuate a line 300 ft long. Further, it does not lose prime if air or gas enters the pump casing and it is therefor suitable for handling hot or volatile products.

The maximum capacity of this type 14 pump is 140 gpm and the maximum head is 130 psi. **Precision Electrical Products (Stockport) Ltd., Lytham Street, Cale Green, Stockport.**

BCE 596 for further information

Transistorized Photoelectric Equipment

New transistorized photoelectric equipment is available in alternative versions for counting or switching applications.

When used for counting applications, the unit is supplied complete with a Series F.43 electromagnetic counter, which is energized directly from a transistor switch circuit. In this configuration the unit is designed to operate up to a speed of 1500 counts/min.

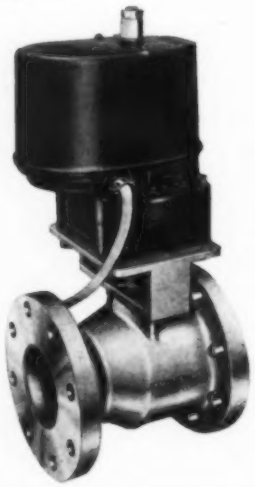
When used for photoelectric switching applications the unit is supplied with an integrally mounted relay having one pair of normally-open and one pair of normally-closed contacts rated at 3 amps at 230 volts A.C. In this configuration the unit is suitable for operation at switching rates up to 300/min.

When used in conjunction with the standard 8-watt remote mounting light source unit, both versions are suitable for operation over range of 25 ft. **Lancashire Dynamo Electronic Products Ltd., Rugeley, Staffs.**

BCE 597 for further information

"Double Seal" Ball Valves

In this design the rotating sphere is located between two patented non-metallic seats. These seats are made in a variety of materials: PTFE, Buna-N, Neoprene, nylon, etc. The seal has a flexible lip which is deflected on assembly to create an initial sealing force independent of line pressure.



The upstream and downstream seats are identical and so the valve can be installed irrespectively of direction of flow. Sealing is effected both upstream and downstream, providing the "Double Seal" safety feature. Further, this ball valve is claimed to require no maintenance.

A new company has been formed to manufacture this valve in the U.K. for world-wide distribution. **Jamesbury-Serck Ltd., Eastern Avenue, Gloucester.**

BCE 598 for further information

New Publications

Flame Spraying Processes. These two 6-page illustrated folders show petroleum and marine applications of Metco flame-spraying processes which apply coatings of monel, brass, bronze, stainless steel, pure zinc and aluminium to repair worn areas of equipment. **Metco Inc., Westbury, Long Island, New York.**

BCE 599 for further information

Classified Index of Ferranti Computer Literature. This publication lists the computers and their associated documents which are available from Ferranti. It should assist the reader to select the computer best suited to his interests. **London Computer Centre, 68/71 Newman Street, London, W.1.**

BCE 600 for further information

Lead Applications to Modern Industry. This 12-page illustrated booklet is a reprint of a paper which E. R. Newson read at the European Conference for Chemical Technology (Achema Congress), 1961. It covers the use of lead in both the chemical and nuclear fields. Copies can be obtained from **Associated Lead Manufacturers Ltd., Clements House, 14 Gresham Street, London, E.C.2.**

BCE 601 for further information

"Tube-in-Strip." This 2-page folder gives details of "Tube-in-Strip" which is a single piece of aluminium providing a combination of parallel tubes and strip material. It is made from corrosion-resistant Impalco aluminium. **Imperial Aluminium Co. Ltd., P.O. Box 216, Witton, Birmingham, 6.**

BCE 602 for further information

Carter "AM" Type Hydraulic Variable-speed Gears. A 10-page illustrated folder, AM/1, gives details of the new 10-hp size hydraulic variable-speed gear AM 26 now available.

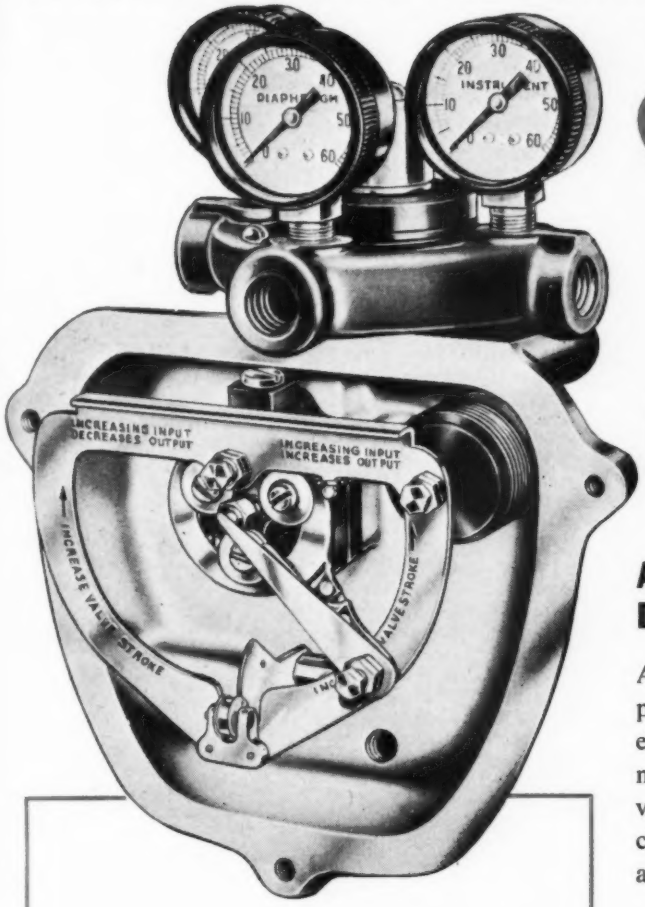
This machine is compact, efficient, totally enclosed, capable of giving a 27:1 stepless variable-speed range from input speed downwards with the facility for picking up full load torque from zero rpm. **Carter Gears Ltd., Thornbury Road, Bradford, Yorkshire.**

BCE 603 for further information

Pore Size Determination. Accurate, simple and quick measurement of the largest hole in a filter element can be made with the Bubble Point Test Stand described in Bulletin A 11. The bulletin includes complete specifications and application data on two types of stand available, one using hydraulic fluid and the other using denatured alcohol as the test medium. All instructions for operation are included on the control panel of the unit. Detection range of the instrument is from 13 to 120 microns. Military and industrial technical manuals on the Bubble Point Test Stand are also available on request. **Aircraft Porous Media Inc., 30 Sea Cliff Avenue, Glen Cove, New York.**

BCE 604 for further information

A new concept in design makes possible the...



FISHER

TYPE 3560
VALVE POSITIONER

V/P

Assured product performance through DYNAMIC ANALYSIS engineering

Application of mathematical techniques of design to pressure control systems has enabled Fisher to eliminate the conventional approach in the development of the new V/P valve positioner. It has provided the V/P with the following combination of characteristics and performance . . . unobtainable in any other type of valve positioner.

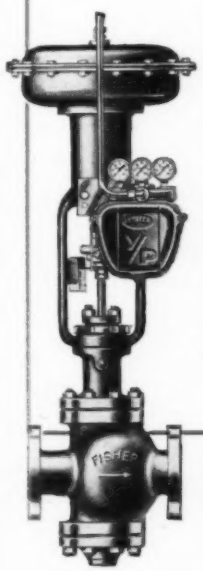
SMALL AND COMPACT . . . only 6⅝ in wide and 8¾ in high (with gauges).

CONVENIENT ADJUSTMENT . . . valve stroke and zero adjustment readily accessible and easy to make.

SPLIT RANGE . . . no parts change whatsoever is required for split range operation.

EASILY REVERSIBLE . . . reversed by simply moving flapper arm from one beam quadrant to the opposite quadrant.

CHARACTERIZED CAMS . . . offer wide flexibility in valve characteristics.



PERFORMANCE DATA

Hysteresis (Average)	0.0012 in
Linearity (with linear cam)	within ± 1%
Open loop Gain (with linear cam)	86
Resolution Sensitivity	0.002 lb/in²
Repeatability	± 0.0003 in
Stroking Speed	0.4 in/s
Air Consumption (Steady State)	10 ft³/h
Break Frequency (5% of instrument pressure range)	3.9 c/s
Break Frequency (3% of instrument pressure range)	4.6 c/s

The above performance data was taken from laboratory tests on a Type 657 diaphragm actuator, Size 40, with 1½ in travel. Instrument range 3 to 15 lb/in².

Write today for Bulletin E-3560

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FG12

World of Chemical Engineering

New Plants in Brief

Petroleum

A new catalytic reformer to produce more premium-grade petrol is under construction at **B.P.'s Kent Refinery**. It will convert low-octane naphtha and benzene into high-octane blending components at the rate of 23,000 brl/dy. Also at the Kent Refinery construction of the **B.P.-California Ltd.** aromatics petroleum chemicals plant is under way.

The Shell Oil Co., of Canada, announce that a new oil refinery is to be built alongside Lake Ontario near Toronto. Expected to be completed in 1963, it will process about 10 million barrels of Canadian crude annually. Included in the installation will be the latest equipment for distillation, flashing, catalytic cracking, reforming and hydro-desulphurization.

The Scottish Gas Board have asked **Humphreys & Glasgow Ltd.** to design and install a £300,000 refinery gas reforming plant at Granton, Edinburgh.

Of Onia-Gegi self-steaming type, which produces sufficient waste heat steam for process use, the plant will comprise two units reforming refinery gas to produce a maximum output of 18,000,000 cu ft per day of 450 Btu town gas. The plant will also be capable of reforming butane if required.

Other new petroleum plants announced include a **Houdry Process Corporation** "Detol" plant with a nominal design capacity of 17 million gal/yr of benzene which has gone on stream at Houston, Texas; and a petrochemical complex to be built by **Dow-Unquinesa**, near Bilbao, Spain. The Spanish Government have granted a permit for the production of 10,000 tpa of high-pressure polyethylene, 6000 tpa of low-pressure polyethylene, 12,000 tpa of styrene monomer and 8000 tpa of polypropylene.

Oxygen and Nitrogen Plants for Export

Three tonnage oxygen and nitrogen plants are to be designed, supplied and installed by **CJB Ltd.** at Tarnow, in the south of Poland. They will be used in the production of ammonia and will have a combined output of about 1000 tpd of oxygen and 1100 tpd of nitrogen. The latter will need to be exceptionally pure to be used in ammonia synthesis.

From South Africa there is news of a new R6m titanium dioxide plant which is under construction at Amanzimtoti on the Natal coast. It will start production in 1962, with a capacity of about 10,000 tpa.

In the field of organic chemicals, **The Allied Chemical Corporation** will construct a phthalic anhydride plant at its El Segundo site near Los Angeles, Calif. The Von Heyden-Chemiebau process will be used because it utilizes a variety of raw materials.

Computers for Process Control

Four digital computers for on-line control computation have been purchased by **Monsanto Chemical Co.** of America. They will be used in Monsanto's new hydrocarbon raw materials plant under construction at Chocolate Bayou, Texas. The computers are being supplied by the American associates of **Honeywell Controls Ltd.**, and will monitor process conditions, making calculations, and furnishing printed instructions to operating staff who will then make the necessary process changes. The world's largest ethylene unit producing 500 million lb/yr will be included in the plant, which will also make benzene, naphthalene, propylene, cumene, phenol, acetone and ethyl benzene.

Honeywell Controls Ltd. are also to supply a computer-directed control system to the **Celanese Corporation** of America for its acetyl manufacturing plant being built at Bay City, Texas.

In England, **Elliott Brothers (London) Ltd.** have created an Automation Analysis Department within their Data Processing Group of Divisions. They have extensive experience of "on-line" and "off-line" applications of computers to industrial processes.

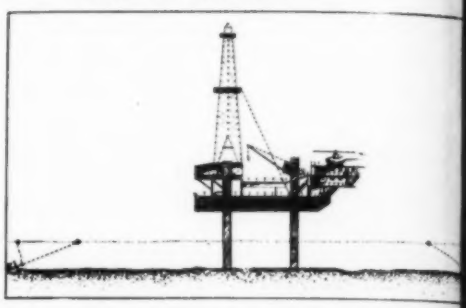
New Processes

In the field of catalytic reforming with platinum catalyst, a halogen is usually a necessary component of the system. However, the **Houdry Process Corporation** have developed a new commercial halide-free platinum reforming catalyst which is being used in Houdriforming units in Japan.

The Road Research Laboratory and **The Natural Rubber Bureau** are investigating the use of rubberized road materials. They say in their report that a method of preparing a rubberized cutback bitumen has been developed using latex in which the temperature of mixing has been kept below that at which degradation on any appreciable scale will occur. By this means, a cheaper form of rubber used more efficiently has resulted in a more economic binder, and the disadvantage of foaming, found previously with latex, has been eliminated.

The unexpected discovery of ions corresponding with groups $(CO_2)_n^+$—whilst examining commercial carbon dioxide with a mass spectrometer—suggests that carbon dioxide may, after all, form polymers. This probability emerged after work at **A.E.R.E. Harwell** and the **Reactor Technology Branch** of the U.K.A.E.A. at Capenhurst. It is probable that the ions observed were formed from polymeric molecules already existing, of the form $(CO_2)_2$, $(CO_2)_3$, etc., continuing in decreasing magnitude as far as $(CO_2)_{23}$.

North Sea Oil Search



The mobile oil-drilling platform "Triton" left Rotterdam on 27 August, 1961, to begin its search for oil in the North Sea, 2½ miles off the coast of South Holland. "Triton" was built at Wallsend-on-Tyne and fitted out at Rotterdam. It is about 125 ft long, 65 ft wide and weighs 2400 tons. Its four legs, each 170 ft long, can raise the platform 40 ft above sea-level.

N.V. Nederlandse Aardolie Mij., which is jointly owned by a company of the **Royal Dutch/Shell Group** and the **Standard Oil Company** of New Jersey, will operate "Triton".

Company News

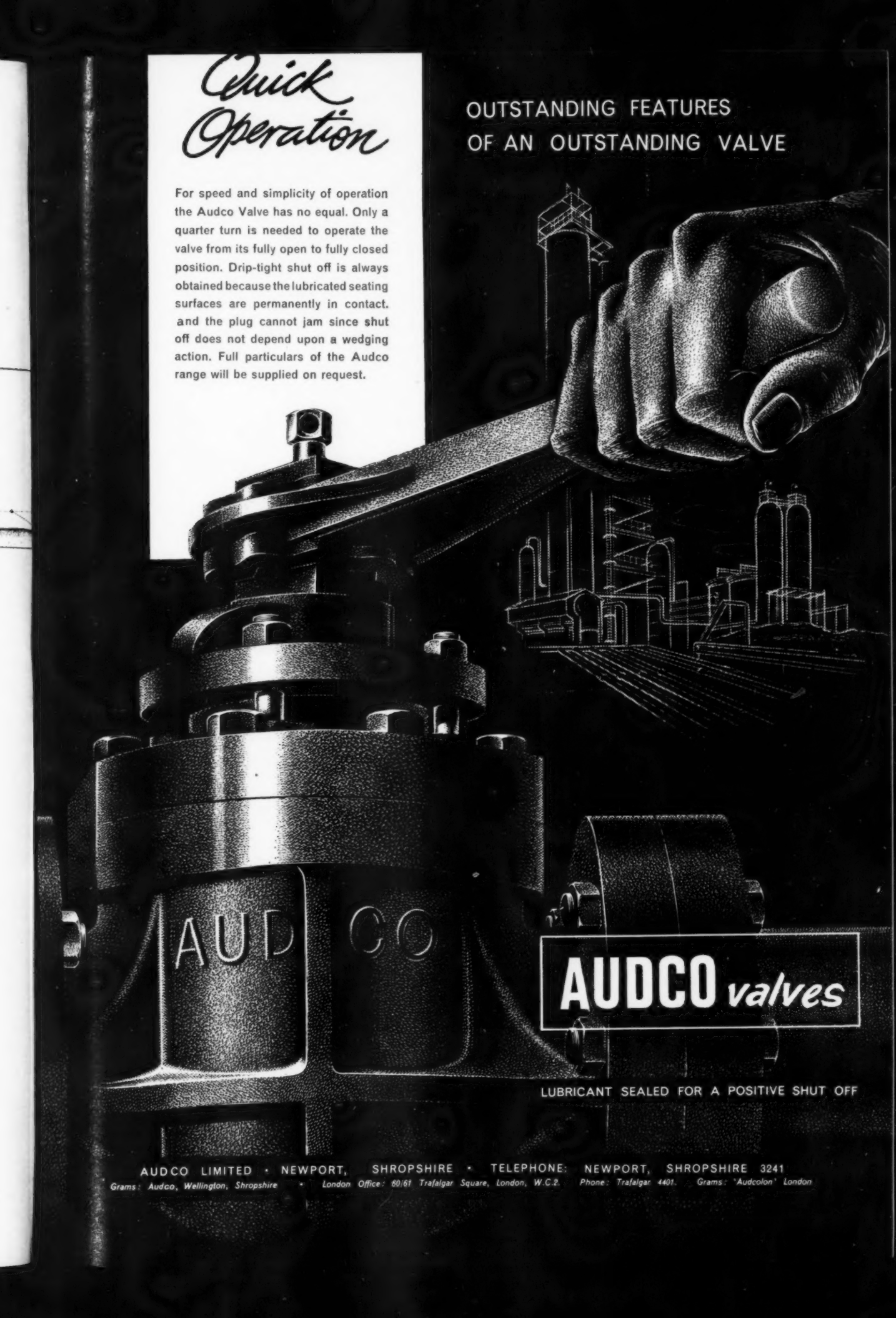
More Overseas Interests by U.S. Firms

Hooker Chemical Corporation of New York are to bring their interest in the Argentine phenol and monochlorobenzene producer **"Duranor"** up to 50 per cent. Another U.S. firm, **E. I. du Pont de Nemours & Co.**, are to form a new company in France. To be called **Dekachimie**, it will be formed with **Etablissements Kuhlmann** of Paris and will sell isocyanates.

Also from America it was announced that **The Atlas Powder Co.** of Delaware have changed their name to **Atlas Chemical Industries Inc.** The sales agents in Britain are **Honeywill Atlas Ltd.** of London.

New British Companies

I.C.I. Ltd. and **E. S. & A. Robinson (Holdings) Ltd.** are entering into an association to develop the uses of plastic films in the packaging industry. The new subsidiary will be called **Robinson Plastic Films Ltd. Uddeholm Ltd.** (the British associates of **Uddeholms A.B. of Sweden**) have inaugurated a Chemical and Nuclear


Quick Operation
For speed and simplicity of operation the Audco Valve has no equal. Only a quarter turn is needed to operate the valve from its fully open to fully closed position. Drip-tight shut off is always obtained because the lubricated seating surfaces are permanently in contact. and the plug cannot jam since shut off does not depend upon a wedging action. Full particulars of the Audco range will be supplied on request.
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Plant Division. It will be concerned with design, fabrication and sales of all types of tanks, pressure vessels, heat exchangers and fractionating columns in stainless and clad steel.

A 14-member panel of export experts to assist smaller firms in the problems of exporting has been organized by the North Midland Regional Council of the **F.B.I.** It covers all the principal industries in that area.

Contracts

Water Treatment

The Neckar Water Softener Co. Ltd., of London, have secured the contract for the water treatment plant in the new power station at Basra, Iraq. They have already installed pre-treatment equipment to deal with 15,000 gal of river water per hour and additional plant for second-stage treatment of 7500 gal/hr of the pre-treated total. Of this, 5000 gal are filtered for general auxiliary services, the remaining 2500 gal being first softened by lime treatment, then filtered and subjected to base exchange treatment, and finally passed to evaporators.

Another export order, this time awarded to **Richardsons, Westgarth & Co. Ltd.**, of Wallsend, is to supply two vacuum flash evaporators each capable of producing 1.4 million gal of drinking water a day to the Government of Curaçao. These units will be the largest vacuum flash evaporators in the world. The order, worth £½ million, is scheduled to be delivered in less than a year.

The U.S. Department of Health, Education and Welfare have issued a contract to **Ionics Inc.** to develop novel ion exchange resins and conduct a study of the use of ion exchange membranes in electrodialysis cells as an advanced method of waste treatment. The aim is to increase fresh water supply by re-use of water rather than desalting sea water.

Back home, **William Boby & Co.** has been awarded contracts by **British Glues & Chemicals Ltd.** for the supply of two de-alkalization-base exchange plants to a value of more than £10,000.

Dust and Fume Removal

Two big orders for precipitators to be used in power stations have been received by **Lodge-Cottrell Ltd.** The first order is for precipitators valued at £1.1 million for four 350-MW boilers at Tilbury power station. The flue dust produced by these four pulverized-fuel-fired boiler units will be partially removed by mechanical collectors, and final cleaning will be carried out by twelve electro-precipitators, three to each boiler unit. The second order, valued at £1.5 million, and representing the largest single order for boiler flue dust precipitators ever received by the company, is for precipitators for the new 2000-MW West Burton power station near Nottingham. Each of the 16 electro-precipitators, four to each of four boiler units, will be of three-stage, horizontal gas-flow, high-efficiency design, complete with the necessary high-tension transformer/rectifier equipment.

Simon-Carves Ltd. have also received orders for two more electro-precipitation plants. Expected to cost about £350,000, they are for the iron and steel industry.

There is also news of a £10 million scheme for the replacement of all existing open hearth steel melting furnaces of **Steel Peach & Tozer Ltd.** by six 110 ton oxygen-lanced electric arc furnaces. **W. C. Holmes & Co. Ltd.** are to supply gas cleaning plant for each of the first two furnaces. Each gas cleaning installation consists of a direct fume extraction system, an electrical precipitator and a common water treatment plant.

Process Control Equipment for Export

George Kent Ltd., of Luton, have received a contract to supply the Polish importing organization, Varimex, with special equipment valued at £30,000, for the measurement and control of processes in their chemical industries. Part of the equipment is to be supplied by **Kent Tieghi SpA**, of Milan.

There is news that the Russians have bought the Panellit 609 computing system which was exhibited by **Elliott-Automation Ltd.** at the British Trade Fair in Moscow. It has been bought by the Committee for Complex Automation in the Chemical Industry for installation in a major chemical plant in the Soviet Union.

From Hungary comes an order for £75,000 worth of electrical controls for a pulp mill at Stalinvaron. The equipment will be manufactured by **Brookhirst Igranic**, a company in the Metal Industries Group.

Other Contracts

In the petroleum field their is news that the **Societe de la Raffinerie de Strasbourg** has selected **Pic Engineering** as contractors for their atmospheric distillation unit and gasoline treating unit to be built at the Strasbourg Refinery. **McKee Head Wrightson**, of London, will provide process design, basic mechanical design and general supervision services. The unit will process 3.3 million tpa of crude from Iraq and Hassi-Messaoud. Also, it has been announced that the **Gas Council** has reached an agreement to buy liquid methane from the Hassi R'Mel gas field in the Sahara. The scheme provides for the importation of about 700,000 tpa of liquid methane from a port near Oran to Canvey Island in the U.K.

Recent contracts for organic chemicals plant include one awarded to **Blaw Knox Chemical Engineering Co. Ltd.** to supply **J. Bibby & Sons Ltd.**, of Liverpool, with a plant for the solvent extraction of soya beans and other oilseeds. The Russians have ordered some more equipment from **John Dalglish & Sons Ltd.**, of Glasgow, for their synthetic rubber industry. Two complete plants, worth £1½ million, for the filtration, drying, wrapping and packing of butyl synthetic rubber are to be delivered between July and December 1962.

A contract for all heat exchanger mountings and steam and feed pipeline valves required at the Sizewell Atomic Power Station has been secured by **Dewrance & Co. Ltd.** The £167,000 order will include parallel slide valves up to 18 in. in size, large-bore strainers, safety valves and water level indicators.

Simon Handling Engineers Ltd. has made an agreement with **International Pulp Products Inc.** for the supply of pulp mills for the paper industry. They hold patents for the "Cusi" process for the use of bagasse, the crushed residue of cane sugar mills. A plant using this process is successfully operating in Mexico.

Personalities

Dr. H. E. Rose, Reader in Mechanical Engineering at King's College, University of London, has been honoured with the title of Professor of Powder Technology in the University. He is a distinguished contributor to *British Chemical Engineering*.

Dr. Leo Marion, senior director of the National Research Council, Ottawa, was elected as president of The Chemical Institute of Canada, and **Dr. Laurence H. Cragg**, vice-president of the University of Alberta, was elected as vice-president of the Institute at its 44th Chemical Conference and Exhibition which was held in Montreal during August.

Other appointments include: **Mr. W. C. d'Leny** to be Chairman of I.C.I. Billingham Division; **Mr. A. R. Milne** to be Managing Director of I.C.I. Fibres Division jointly with **Mr. E. B. Abbot** and **Dr. F. J. Siddle**; **Mr. J. D. Holland** to be a Director of The Severn Instrument Co.; **Dr. F. C. Lloyd** to be Development Director of F. W. Berk & Co. Ltd.; and **Mr. G. H. Duffield**, who is a director of Stockdale Engineering Ltd., to have a seat on the board of Lightnin Mixers Ltd. **Dr. D. Train** has resigned his Readership in Pharmacy in the University of London and is joining Cremer & Warner, consulting chemical engineers, as a Partner.

Problems Solved

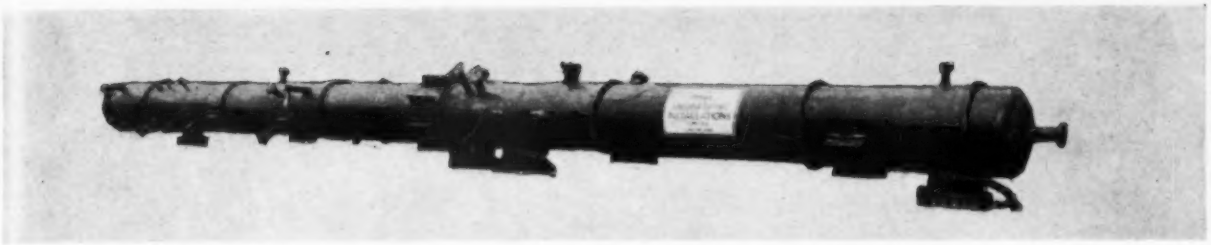
Reduced Downtime on Parchment Machine

Part of a process at a parchment manufacturing company's plant* consists in running wood pulp sheet through sulphuric acid baths under controlled conditions. The acid dissolves the wood fibres to form a jelly-like substance called an amyloid. This fills the spaces between interlaced fibres and changes the sheet into a film-like material called vegetable parchment paper.

These parchment machines use many rubber-covered rolls some of which squeeze excess acid from the sheet. When the rubber on these press rolls etches and swells, the rolls are removed and the rubber ground true again.

Since a set of Hypalon-covered rolls were installed on one machine, performance has greatly improved, and it is estimated that Hypalon-covered rolls will give at least 2½ times the service life of the previous acid press rolls.

* K. V. P. Sutherland Paper Co., Kalamazoo, Michigan, U.S.A.



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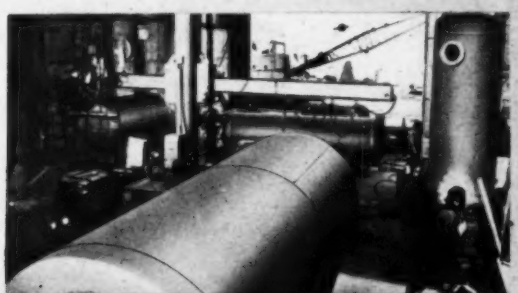

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919

Speedy Compressor Repair

Production at a large chemical manufacturing company was recently reduced due to a partial seizure of a compressor cross-head, which had resulted in a badly cracked and "fired" lower cross-head guide.

On a previous occasion the repair had been carried out in six weeks using a specially constructed boring bar. This time a company* with experience in cylinder regrinding with Master-Hone equipment was consulted.

Following the metal stitching of the lower guide, the original surface finish of the lower "fired" guide was restored by regrinding and honing. The top and bottom guides, which take the form of two arcs 16 in. dia. by 2 ft 6 in. long, gave a total circumferential contact surface over about one-third of a circle. It was considered necessary to support the regrinding and honing tool head over the whole circumference, and latticework side guides were constructed to complete the cylinder between the top and bottom guides.

The cross-head was machined in three days to the required accuracy of alignment and a surface finish equal to that of a new machine. The Master-Hone repair was speedier, less costly and produced a better finish than the boring bar method.

*Nicol & Andrew Ltd., 20 Kelvin Avenue, Glasgow.

Filtration of Radioactive Chemicals

In the treatment of irradiated uranium fuel elements from the Calder Hall and Chapelcross nuclear power stations, which is carried out at the U.K.A.E.A. plant at Windscale, an exacting filtration problem arises. Thus, when the fuel element cans have been removed the uranium rods are dissolved in acid to permit the separation of the plutonium fission products and uranium by solvent extraction. The solution, in order to protect pump valve packs and other equipment in the liquid chemical lines, has to be filtered. This requires a material which is mechanically strong, chemically inert and which has large volume flow-low pressure drop characteristics.

These conditions were fulfilled by a system of filtration candles,* varying in length from 6-18 in. and in diameter from $1\frac{1}{2}$-5 in., which are constructed from high-density polyethylene of the Ziegler type. This material (Vyon) is free from detachable fibres and is easily machined and fabricated.

* The candles are manufactured by Porous Plastics Ltd., Dagenham Dock, Essex.

Long-Life Submersible Nitric Acid Pumps

About a year ago, a chemical manufacturing company* considered that a titanium pump, designed to handle 99.8 per cent nitric acid, would give longer life and require less maintenance than their existing pumps made of cast 18/8/Nb alloy.

As a result of discussions with a firm of chemical pump makers,† a suitable submerged pump was designed which ensured reliability and safety, and required little maintenance while pumping this highly corrosive acid, since the gland is not under the liquid.

The submerged length of the pump was to be about 8 ft 9 in., and centre steady bearings were needed along the support tube. With a view to increasing the rigidity of PTFE bearings (previously developed by the pump makers for handling HF for the U.K.A.E.A.), comparative tests were made on PTFE loaded with molybdenum disulphide and stainless-steel powders. The molybdenum-loaded bush swelled considerably, but the stainless-steel-loaded bush was satisfactory.

This titanium submerged pump has now operated satisfactorily for over 10 months (7000 hr) at 1440 rpm, and another three pumps have replaced those made in 18/8/Nb alloy.

On account of the limitation in the size of pumps which can be lined, these units have been designed to suit welded fabrication techniques. Instead of using a cast iron casing to provide the required strength, the makers have used a slightly heavier gauge titanium and applied stiffening ribs where necessary. There is, therefore, no limit to the size of pump which can be economically made.

* I.C.I. Nobel Division.
† Appleton & Howard Ltd.

Remote Supervision by Telephone

The Datafonic system of supervisory control, using public telephone lines, has been installed commercially for the first time at an oxygen plant in Brinsworth.*

Manual supervision of the plant will be unnecessary. Approximately 40 alarm conditions have been determined and split up into four groups to simplify fault detection. Any fault in one of these groups causes the Datafonic equipment to sound the appropriate alarm—the unit automatically dials the central control room and transmits a verbal message informing control on what has happened.

Should central control wish to interrogate the plant, this is done simply by dialling the appropriate telephone number and the Datafonic equipment will give its verbal message. In addition, normal speech facilities exist over the interconnecting telephone circuit.

In the event of air-compressor failure the entire plant shuts down and the appropriate Datafonic message is given. Of the numerous other alarm conditions, some would likewise merit speedy attention, although the operation of the plant might not be affected.

In order to isolate any particular fault a special panel has been installed which contains indicators for each of the alarm conditions. The service engineer need only check which of these indicators have operated to know where the fault lies.

The Datafonic equipment at Brinsworth will initially operate over a private telephone line, although the system can operate over either manual or automatic telephone networks. When operating over G.P.O. lines the Datafonic installation can be interrogated by field engineers from a public telephone kiosk.

* British Oxygen Co.

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Can. J. Ch. E., 1961, **39** (1), 46-8.

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Y. MORITA, K. YAMAMOTO
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